ASSESSMENT OF LOW BACK INJURY RISK IN RESIDENTIAL CARE WORKERS

By

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ABSTRACT

Low back injury continues to be a problem for residential care workers. There is an absence of an assessment tool that will determine probability of low back injury based on occupational exposure. This study analysed injury incidence among residential care workers and determined perceived stress and exertion, hand forces, postures, and task frequencies encountered in routine work tasks. Biomechanical analysis determined joint forces at the low back to be in the range of 467N to 3811N compression and 66N to 471N A-P shear over all tasks. Task frequencies, joint compression forces, population low back injury data and material fatigue characteristics were used to model risk of low back injury as a function of occupational exposure. The fatigue model predicts that 50% of residential care workers will experience a low back injury by their eighth year of work experience, and 95% by their fifteenth year of work.

EXECUTIVE SUMMARY

The risk of musculoskeletal injury to residential care workers is well documented in the literature. Historically, residential care has had a higher rate of injury when compared to the entire healthcare industry. Of all injuries, low back injuries occurring during patient handling tasks are the most frequent type of injury sustained by residential care workers.

Previous research has shown that peak loading and work history are correlated with risk of injury. However, the nature of the relationship between these parameters is not clearly defined. This research project addresses the hypothesis that a model can be created that will predict probability of low back injury based on a function of peak loading of the L4/L5 spinal joint, material properties and occupational exposures over an entire working career. The research was divided into four studies.

Study I examined historical injury data among residential care workers, as well as perceived levels of stress and exertion and perceived contributors to injury in the work environment. Injury data collected over a 5 year period were extracted from an employer's injury database, and filtered to exclude any repeat low back injuries. 159 injury records were identified, providing a mean injury rate of 5.6% per year (SD=6.4) in a population of 578 workers. Results show that the most stressful tasks were in-bed care tasks. When compared to a previous study, the results show a shift from manual transfer tasks to the in-bed tasks as the tasks most perceived to be significant contributors to injury.

Study II examined a comprehensive list of tasks performed by residential care workers in six care units. Biomechanical analysis was performed to analyse

the L4/L5 joint forces, including joint compressive force, A-P and lateral shear forces and joint (extensor) moment. Results indicate that workers experience peak compressive loads of 467N to 3811N and peak A-P shear loads of 66N to 471N. One task exceeds the NIOSH-recommended compression force limit of 3400N, and a further four tasks are within 204N of the NIOSH limit. These four tasks have a mean compression force of 3207N and together are performed approximately 30 times per shift. Results suggest that the high incidence of low back injury observed in residential care workers is related to the peak compressive loads and the frequencies with which these tasks are performed.

Study III examined the relationships of subjective measures of perceived stress and exertion at the low back to objective measures of hand force, calculated values of joint moment and forces at the low back and trunk posture. There was a low correlation between the subjective and objective measures. There were strong correlations between subjective measures of ranking (stress) and rating (exertion), and among objective measures of hand force, L4/L5 joint compressive force, A-P shear force, joint moment and trunk posture ($p<0.05$). Hand force was also found to be positively correlated with subjective rating of exertion ($r=0.45$, $p=0.03$).

In Study IV, a low back injury model was developed that uses material fatigue theory to predict the onset of low back injury as a result of cumulative loading. The model's inputs are peak L4/L5 joint compression forces and task frequencies. Model parameters were adjusted to obtain a best fit prediction of low back injury data. A cumulative probability distribution curve was generated from the model output to illustrate the behaviour of injury development over a full time working career. The fatigue model predicts that 50% of residential care

workers will experience a low back injury by their eighth year of work experience. It is concluded that, while this model provides a good prediction of injury risk in residential care workers, the model needs to be further refined to incorporate more comprehensive low back injury data, shear forces, visco-elastic effects and an improved database for in-vivo material properties of the lumbar spine.

DEDICATION

There are three groups of people to whom this work is dedicated.

This work is dedicated to the front-line care workers providing hands-on care to our senior citizens and veterans in the extended/residential/complex care facilities across British Columbia. Over the past few years, I have spent considerable time in residential care facilities, talking with the workers and observing care. I have developed a deep appreciation and a great deal of respect for the care that is provided and the workers that provide that care. The individuals I have met and gotten to know have shown me the deep commitment they have to their residents and their care.

This work is also dedicated to my colleagues, my fellow ergonomists. It is my hope that this work will be the starting point for greater work to be performed in the coming years. I have had the good fortune to be a part of these initial steps, and I only hope to pursue this work further with the goal of having more objective tools for use in ergonomics and human factors in applied and research settings. As a practitioner, I have a vested interested in the development of an applied tool for use by myself and my colleagues.

Last, but not least, this work is dedicated to my family. My wife Heather has supported me throughout this process. I have been blessed with two wonderful children, Hanna and Connor, who both arrived during the course of this research. I have made a point to spend as much time as possible with them in these early years, and I am glad I did. Not the content as much as the process of completing this work has taught me many things, a few of which I wish to pass onto my children. If nothing else, I want to impart my sense of curiosity and inquiry to my kids; I feel that there are not enough people out there asking, "But why is it like that?" I also want them to know that just because a situation may appear difficult, you should not be afraid to try. The only real way to learn is to make mistakes, but the only way you can make mistakes is if you attempt.

ACKNOWLEDGEMENTS

This work could not have been accomplished without the help, encouragement and support from a number of individuals.

Dr. Dan Robinson had a lot to do with my pursuit of this work. Dan, thanks for your encouragement, your context, and for sharing your experience with me. You didn't tell me I should do it, but you didn't tell me I shouldn't either. I did it anyways, and I'm glad I did. Your support throughout this process has not gone unnoticed or unappreciated. Thank you for your support over the past few years, I am fortunate to know you.

I would also like to thank Carol McGrandles for encouraging me to pursue this work so that I can better myself. Your support at the beginning meant a tremendous amount me then, and still does now.

There are a number of people in my department I also wish to thank: Kelly Duke and Deanna Harrison, my friends and colleagues, for helping me out in the data collection stages and during write-up. A thank you to Geoff Crampton, Vice-President of Human Resources, Dave Keen, Director of Workplace Health, and Betty Johnson, my Manager, for supporting my work within and outside our department. And thanks to Quinn Danyluk, for being a sounding board and your general level of tolerance.

I would also like to acknowledge the Workers' Compensation Board of British Columbia, whom, indirectly, supported this work through their "No-Lift" initiative funding, provided to the BC healthcare industry in 2002. This research was conducted as a part of the methodology development for the Safe Client Handling Program in Fraser Health.

Finally, I wish to recognize Dr. James Morrison, who has provided me with innumerable hours of his time, expertise and insight into the field of ergonomics. He has influenced me in my decision to pursue this field, and was kind enough to take me on as a graduate student. The experience I have gained has been tremendous.

Thanks Jim.

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GLOSSARY

LBI	Low Back Injury - A musculoskeletal injury to the low back area. The types of LBIs referred to in this paper include those that occur during the normal course of work. This categorisation excludes those LBIs that occur as a result of direct or indirect forceful trauma that may be associated with an accident (e.g., slip or fall) that are not routine occurrences within the job duties.
RCAs	Resident Care Attendant - A term that refers to all direct-care givers working in residential care settings. These individuals perform the more physically-demanding work such as toileting, bathing, dressing and transferring residents
patient handling	Activities that involve a caregiver providing physical assistance to a dependent or semi-dependent patient or resident for the purposes of moving that patient or resident. This movement is either over a short distance (i.e., bed to wheelchair), or may involve movement within the confines of a surface (i.e., turning in bed)
FTE	Full Time Equivalent - The unit of measure used in the denominator of injury rate reporting. One FTE represents the number of hours worked by a single worker employed full time. Two workers working half time each (0.5FTE) is equivalent to one FTE.
UCS	Ultimate Compressive Strength - The parameter that describes the strength of a material. It is the applied load at which structural failure of the material occurs.

REVIEW OF EXISTING LITERATURE

Scope of the Problem

Low back injury (LBI) is the most common type of work-related injury suffered by workers in British Columbia (BC), accounting for 25% of all injuries reported to the Workers' Compensation Board of British Columbia (2002). Tables 1 and 2 provide data comparing the incidence of back injuries to all injuries and other strains, respectively. These data indicate that back injuries present the majority of any one kind of injury and strain observed in the workforce within British Columbia.

Table 1. Injury data across all industries in British Columbia (adapted from WCB of BC, 2002)

Year	Number of Back Injury Claims	Total Number of Claims	% Back Injuries	Days Lost for Back Injuries	Days Lost for all Injuries	% Days Lost due to Back Injuries
1992	20900	81488	26%	923000	3430119	27%
1993	20750	81003	26%	841900	3102791	27%
1994	19540	79503	25%	832700	3271064	25%
1995	19760	78400	25%	806800	3211740	25%
1996	18450	73840	25%	693500	2842111	24%
1997	18780	75124	25%	721900	2981280	24%
1998	18730	72795	26%	784100	3319300	24%
1999	17900	71343	25%	830600	3606932	23%
2000	18250	72314	25%	794200	3491934	23%
2001	17420	68334	25%	784300	3370562	23%

Table 2. Back strains compared to all strains (adapted from WCB of BC, 2002)

Year	Back Strain	Other Strain	Total	% Back Strains of All Strains
1997	18,780	19,810	38,590	49%
1998	18,730	20,640	39,370	48%
1999	17,790	21,080	38,870	46%
2000	18,250	21,240	39,490	46%
2001	17,420	20,730	38,150	46%

In a focus report on work-related injury in healthcare, the Workers' Compensation Board of British Columbia reported that back injuries accounted for 36% of injuries in healthcare during the period of 1994 to 1998. In addition, 38% of all injuries reported were related to patient handling for the same period (WCB of BC 2000). More recent statistics indicate that the prevalence of patient handling injuries remained high through 2001, with 34% of time loss injuries and 41% of all healthcare claims costs in BC associated with patient handling tasks (WCB of BC 2002). When compared to all other industries in BC, healthcare had the highest number of overexertion claims (5,255 reported injuries), the highest number of days lost (412,000 days) and the greatest short-term disability claims costs ($48 million) in 2001 (WCB of BC 2002). These data are shown in Figures 1-3 below.

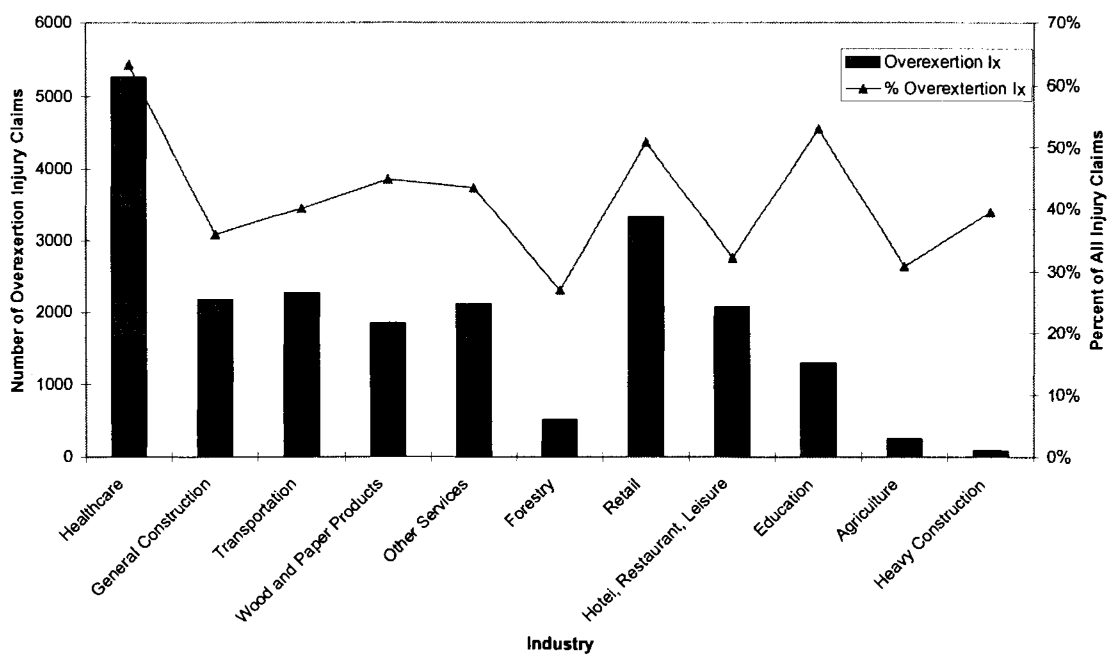

Figure 1. 2001 Days Lost and Percent of All Days Lost in BC, by Industry (adapted from WCB of BC 2002)

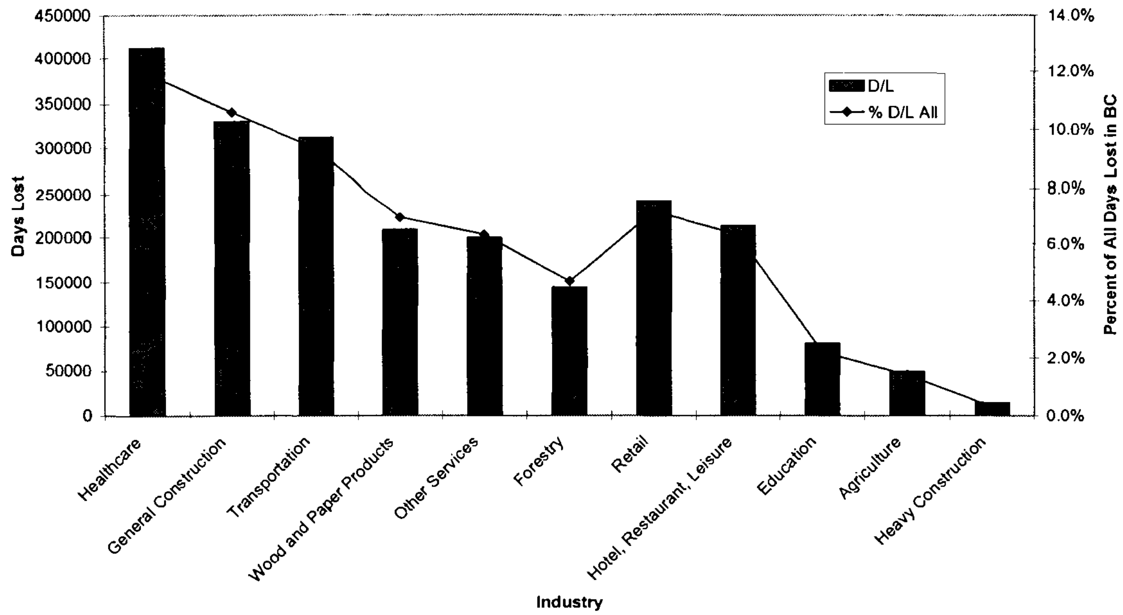

Figure 2. 2001 Days Lost and Percent of All Days Lost in BC, by Industry (adapted from WCB of BC 2002)

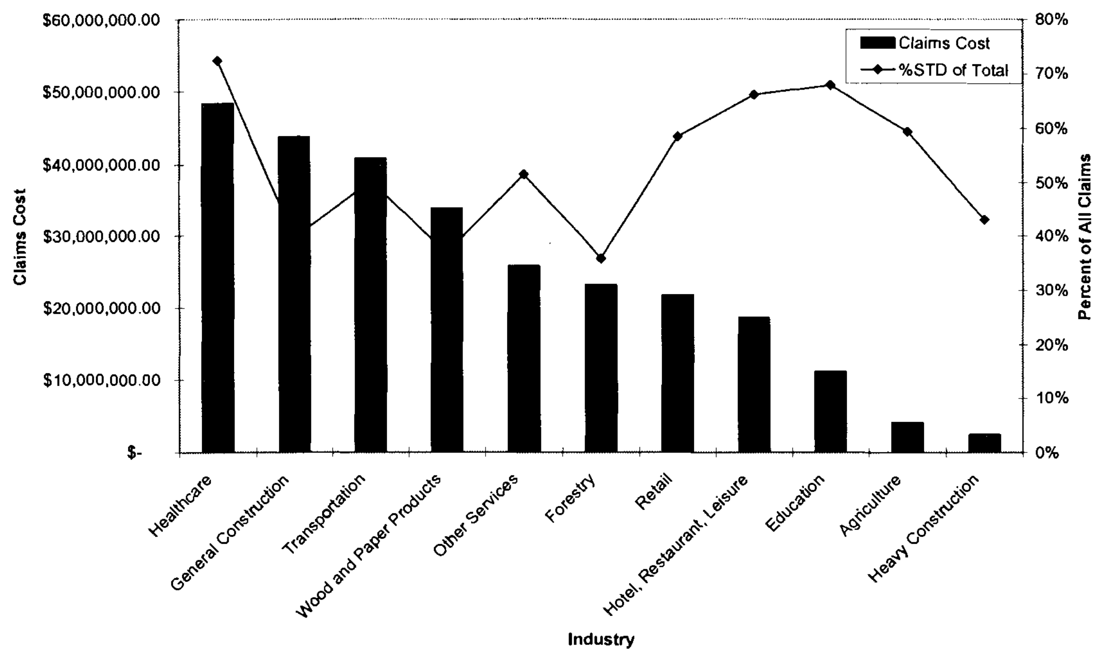

Figure 3. 2001 Claims cost and percent of all claims costs for short-term disability claims (adapted from WCB of BC 2002)

While the residential care industry represents a smaller proportion of the total healthcare worker population in British Columbia, they are experiencing higher injury rates than the average for the whole healthcare industry. Figure 4 shows that over the five years of data from 1994 to 1998, the average injury rate (number of claims per 100 Full Time Equivalents) was 8.9 for residential care versus 7.4 for the whole industry (WCB of BC 2000).

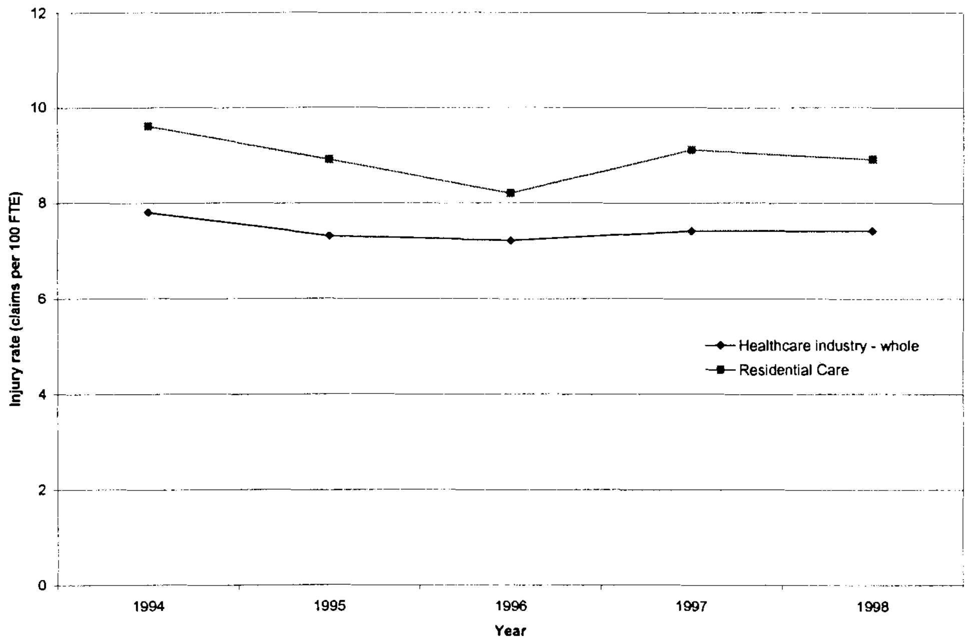

Figure 4. Injury rates for residential care and the entire healthcare industry (adapted from WCB of BC 2000)

Long-term care workers, nurse aides, licensed practical nurses and care aides accounted for 61% of all injury claims in the residential care industry from 1994 to 1998, with 64% of them as overexertion injuries occurring during patient handling tasks. Fifty percent of these overexertion injuries were back injuries (WCB of BC 2000). The injury data provide the underlying reasons for assessing the risks of low back injury in residential care workers.

The literature reflects these injury statistics. Patient handling tasks in healthcare have been identified as a high-risk task group in studies where historical data were examined (Bewick & Gardner 2000), where workers were questioned immediately post-injury (Engkvist *et al.* 1998, Yassi *et al.* 1995), and through assessments with biomechanical models (Holliday *et al.* 1994, Laflin and Aji 1995, Lynch & Freund 2000, Marras *et al.* 1999). Nursing staff who provide care to patients requiring considerable physical assistance suffer a high incidence of LBI (Jensen 1990). Jensen performed a meta-analysis of six studies that examined rates of injury among different groups of caregivers in separate healthcare populations. The results of each study were grouped based on exposure levels and health outcome measures. Exposure levels were categorized into two groups based on the frequency of patient handling tasks; health outcomes were as defined by the researchers of each original study. The absolute difference and relative ratios of prevalence rates were compared for high and low frequency patient handling groups. Jensen found that the high frequency patient-handling group consistently had a higher prevalence rate for negative health outcomes (injury) when compared to the lower frequency patient handling group. The author then calculated the average PR difference and PR ratios by taking into account the size of each study's subject pool. When calculated, the author found that the weighted average prevalence rate for the patient handling groups was 10.5 percent higher than the lower frequency group, and that prevalence rates were 3.69 times higher than the lower frequency group (Jensen 1990). However, upon recalculation using Jensen's data, the rate actually found to be 2.09.

Efforts have been made in the healthcare industry to identify tasks that are in greatest need of intervention. Engkvist *et al.* (1998) examined the accident process leading up to back injuries in nurses. Injured nurses frequently reported lifting or transferring into or out of the bed, and repositioning in the bed as tasks that caused the injury. Yassi *et al.* (1995) took a comprehensive approach to identifying the contributing factors to injuries in nurses by performing individual interviews with injured nurses as soon as possible after injury using a list of standardized open-ended questions regarding the nurse's perceptions of their injury. Gender did not have a significant effect on risk of injury. While seniority was not found to have a significant influence on risk of injury, age was shown to be a significant risk factor. Injured nurses were at least two years younger than non-injured nurses in both study and control groups. Based on these age-related findings, it would need to be determined whether age as a risk factor has its basis in physiological or behavioural factors for effective intervention design. Of the 416 incidents that were examined during the two-year period, the most commonly reported activities at the time of injury were lifting (n=94, 22.6%) and transferring (n=97, 23.3%) patients with assistance from another caregiver.

Owen *et al.* (1992) asked 57 nurse aides to rank 16 tasks in their patient care duties from most stressful to least stressful. The most stressful tasks identified in this study included patient transferring and/or lifting to and from the bed, to and from chairs, and repositioning the patient in bed.

The literature currently available on the risks for low back injury for direct caregivers in the healthcare industry indicates that it is important to have a reliable and valid tool to assess the degree of risk to the worker. It is reasonable to assume that any tool that accurately assesses risk would need to consider the variety of tasks performed (including the specific types of healthcare tasks) and the mechanism of low back injury. The literature is rich with evaluation of risk factors for LBI, and a discussion follows of the criteria that have commonly been examined in the ergonomics literature.

Criteria for Assessing Risk of Low Back Injury

In order to design interventions that reduce risk of injury and to understand where these interventions are most needed, knowledge of maximum safe exposure levels is required. The criteria that are used to define exposure thresholds generally fall into one of three categories: physiological criteria, psychophysical criteria, and biomechanical criteria. Physiological criteria refer to capacities of the human metabolic system to maintain levels of energy supply and waste product removal without excessively burdening the physiological system. Psychophysical limits refer to loads or task rates that are based on the workers' perception of what they are capable of performing. Biomechanical limits are concerned with the loads that are experienced at specific joints or in specific tissues within the human body and have a basis in tissue tolerance for applied stress.

Physiological criteria

Physiological criteria are often considered in the design of safe working tasks. This criterion is based on the assumption that muscular fatigue could lead to reduced strength and stability during the performance of a task, leading to increased likelihood of an injury (Mital *et al.* 1993). Jorgensen *et al.* (1988) and Sjogaard *et al.* (1986) found that after only one hour of 5% MVC isometric contractions, MVC decreased by around 12%, indicating the muscle has fatigued. Based on similar information obtained from earlier research, Jonsson (1978) recommends that static load levels at work should not exceed 2-5% MVC and that load peaks should not exceed 50-70% MVC.

The NIOSH equation (Waters *et al.* 1993) was first published in 1981 and was revised in 1991 by a committee. It follows the form of:

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM$$

where

RWL	= recommended weight limit (kg);
LC	= load constant (23 kg);
HM	= horizontal multiplier ((25/H), cm);
VM	= vertical multiplier ((1-(0.003|V-75|)), cm)
DM	= distance multiplier ((0.82 + (4.5/D)), cm);
AM	= asymmetric multiplier ((1-0.0032A), degrees);
FM	= frequency multiplier (from look-up table);
CM	= coupling multiplier (from look-up table).

The design of the NIOSH equation considers biomechanical, psychophysical and physiological criteria. The physiological criterion is designed so that whole body fatigue is prevented. This criterion was determined to be 9.5 kcal/minute, which would account for approximately the 50th percentile of the female population. The 1991 Committee chose the higher percentile criterion but acknowledged that it may not protect all workers, especially older workers. While the 1991 NIOSH equation does account for upper-body-dependent tasks, it does not address the physiological effects on the lower back musculature. The authors also acknowledged that even though this criterion may prevent whole-body fatigue, it may not prevent injury to the lower back since it would not protect the lower back structure from the cumulative effects of repeated loading.

To provide a more focused evaluation for healthcare, Hui *et al.* (2001) examined fatigue in nurses working an 8-hour shift on a geriatric ward in a Hong Kong hospital. A significant shift in median frequency of the EMG of the erector spinae was found when nurses performed isometric extension at the low back before and after their 8-hour shift. They determined that this median frequency shift is indicative of localized muscle fatigue in the erector spinae at the L4/L5 level. This condition could lead to increased risk of injury through either underestimation of the load leading to an overexertion injury at the low back, or by increasing the load on the passive structures of the lumbar spine leading to musculoskeletal strain. However, the researchers did not provide any injury statistics for their study unit to substantiate the increased risk as predicted by the presence of localized muscular fatigue at the end of the nurses' shifts. Indeed, a number of researchers have stated that there is little epidemiological data available to support the causative relationship between physiological demands and LBI rates in industry, or that the modification of task design to meet the physiological criterion would avoid risk of LBI in an occupation involving considerable manual materials handling (Mital *et al.* 1993, Waters *et al.* 1993, Dempsey 1998).

Psychophysical criteria

Snook & Ciriello (1991) and Mital (1992) outlined safe limits in tabular format for lifting, lowering, carrying, pushing and pulling tasks. The psychophysical methodology involves the performance of the tasks by subjects who then modify the weights handled in the tasks to a perceived acceptable level (Ayoub & Dempsey 1999). Snook & Ciriello's approach required the subjects to project their abilities from 40-minute tasks during a maximum 4-

hour testing session to an 8-hour workday (Snook & Ciriello 1991). Mital (1992) combined the results from two previous studies to create one comprehensive database; the data collected in one study was based on extrapolations from 25-30 minutes of task performance in the lab, whereas the other study required the subjects to perform the task for the entire 8-hour duration.

It is reported that the intent of psychophysical limitations for manual material handling is to reduce the exposure of the worker to stresses that may be beyond the body's limits for fatigue, discomfort and injury (Ayoub & Dempsey 1999). The assumption is that if workers avoid becoming tired, they are less likely to experience injury due to fatigue. While the workers may subjectively judge their level of tiredness, it is unlikely that they can determine the level of loading that is likely to lead to tissue damage through repetitive loading. The instructions provided to subjects in previous psychophysical studies did not mention the term "injury" anywhere in the text (Ayoub & Dempsey, 1999).

Several studies have examined combination tasks (Ciriello *et al.* 1990, Jiang *et al.* 1986) where only lifting, carrying and lowering movements were performed together. While these combination tasks replicate more realistic work tasks, the method does not extend to environments where a range of different handling tasks must be performed in the workday. To address this issue, Mital (1999) examined two case studies where psychophysical tables were used to examine a multiple activity task. Mital examined each activity within the task separately, using the characteristics of the activity to calculate a risk potential (as described in Mital *et al.* 1993) for each task. Mital concedes in his conclusions that future validation studies are still required to confirm that a reduction in one or all of the risk potentials for each activity within a task will lead to an actual reduction in injury incidence.

Biomechanical criteria

The ultimate compressive strength of the lumbar spine has been used to define biomechanical lifting limits for occupational tasks in a number of different risk assessment models (Mital *et al.* 1993, Waters *et al.* 1993, Marras *et al.* 1999). The assumption used was if the task can be designed to reduce the compression on the lumbar spine to a fraction of the ultimate compressive strength (e.g., 30% of female ultimate compressive strength at L4/L5), then risk of LBI is mitigated for that working population.

The ranges for ultimate compressive strength of lumbar vertebrae reported in the literature have been within similar ranges: between 2000 and 12000N (Brinckmann *et al.* 1989), 1520 and 11000N (Hansson *et al.* 1980) or 3698 and 12981N (Hutton & Adams 1982). All of the above data were based on testing using lumbar motion units or vertebral spinal units from cadavers. These tissues were subjected to repeated loading using an oscillating axial-loading apparatus.

The NIOSH equation recommends a maximum spinal compression of 3.4kN at the L5/S1 joint during occupational activities (Waters *et al.* 1993). This limit has been related to risk of injury through consideration of cadaveric vertebral segment failure data (see Waters *et al.* 1993). Waters *et al.* (1993) referenced published data indicating ranges in ultimate compressive strength from 2.1kN to 9.6kN. Jager and Luttman (1989) demonstrated a mean ultimate compressive strength of 4.4kN with a standard deviation of 1.88kN. The data referenced by Waters *et al.* (1993) indicated that if a normal distribution was assumed the data would show a load tolerance of 3.4kN for approximately 30% of the working population. Other studies of reviewed by Waters *et al.* (1993) examined compression at the lumbar spine for specific occupations. These studies revealed a higher rate of LBI for occupations that had average compressive forces greater than 3.4kN (Anderson 1983), 4.5kN (Herrin *et al.* 1986) or 5.34kN (Bringham & Garg 1983). Ultimately, however, the 1991 Committee selected 3.4kN as their criterion compression force limit, but acknowledged that there were data to indicate that increased risk of LBI can occur at average loads of less than 3.4kN (Waters *et al.* 1993).

Injury threshold values for shear force in the spine are less well defined and have received attention only recently. McGill (1997) reported shear tolerances in human spinal units to be between 750N and 1000N, and Marras *et al.* (1999) has suggested a maximum shear value of 1000N. Yingling and McGill (1999) have found an average shear limit of 1540N in a porcine model.

Current Assessment Tools for Evaluating Risk of Low Back Injury

There have been a number of different methods developed over the years that consider the criteria described above in an effort to create a tool that can be used to assess risk of LBI in a work environment. A number of models currently available are described below.

Combined assessment methods

The NIOSH equation, first published in 1981 and revised in 1991, is likely the most commonly used model for assessing risk of injury to a worker. The paper written by Waters *et al.* (1993) discusses the reasons for choosing the various limits for the equation. They identify that the three different criteria - biomechanical, physiological, and psychophysical limits - often conflict with each other, a finding that is supported elsewhere (Dempsey 1998). Waters *et al.* (1993, 1994) list the numerous limitations in applying the equation. It is not appropriate to apply the equation in restricted work environments or with loads whose center of mass may change during the task. The equation also assumes that other tasks performed within the workday do not account for more than 10% of all the workers' tasks.

Mobilizing a patient requires that the patient's centre of mass moves and changes position as their posture changes throughout the transfer task. Providing nursing care to patients and residents involves several tasks that require substantial efforts (Owen *et al.*, 1992). Garg *et al.* (1992) reported that the category of "other" tasks had a mean frequency of 23.3 over the course of a nurse's aide's four-hour shift, while all other tasks listed and examined accounted for a frequency of 25.4 per four hour shift. Since the use of the NIOSH equation assumes that tasks that cannot be analysed using the equation should not amount to more than 10% of the total time in the job, data from Owen *et al.* (1992) suggests that the application of the NIOSH equation to patient handling activities is inappropriate.

Waters *et al.* (1993) also mention that there is a paucity of epidemiological evidence to support the causal relationship between the criteria and the relative risk of injury. Other studies also report a lack of epidemiological evidence to support the NIOSH equation (Dempsey 1998, Kumar & Mital 1992). Waters *et al.* (1993) and Hignett & McAtamney (2000) specifically identify the inability of the NIOSH model to be applied to the handling of people as the justification for the need to develop an assessment method specifically designed for the healthcare work environment.

Nursing-specific assessment methods

A number of attempts have been made to apply known methods for assessing risk of injury to nursing tasks (Marras *et al.* 1999, Kjellberg *et al.* 2000, Engles *et al.* 1994, Steinbrecher 1994). The injury risk model used by Marras *et al.* (1993) is based on repetitive, manual handling tasks in an industrial context. While valid in that industrial context, there may be limitations in the application of the model in the healthcare industry due to the difference in the task performance (i.e., handling boxes versus handling people) and work pace (i.e., highly repetitive versus relatively less frequent). Yassi *et al.* (1995) reported that lifting or transferring a patient with another caregiver was the most common activity at time of injury, while Marras *et al.* (1999), using their injury risk model, reported it to be a safer (i.e., lower risk) task than transferring a patient with only one caregiver. The average lift rate used in the development of the model (Marras *et al.* 1993) was 176 lifts per hour, which is much higher lift rate than what is typical for patient handling in residential care. The effects of rapid, repetitive work and infrequent heavy work (typical of residential care attendants) have different injury risk implications (Ayoub *et al.* 1999).

Despite the high incidence of musculoskeletal injury to healthcare workers, little has been done to validate a dose-response model explaining the relationship between exposure to healthcare work tasks and the probability of developing LBI. Three models have been used to categorize work tasks into high or low priority for ergonomic intervention (Karhu *et al.* 1977, Jensen 1990, McAtamney & Corlett 1993) and only one of these models was designed into a workplace assessment tool designed to specifically target patient handling tasks (Hignett & McAtamney 2000). Unfortunately, these models only prioritize tasks for intervention and do not explain the mechanisms that precipitate injury.

The "Rapid Entire Body Assessment", or "REBA" (Hignett & McAtamney 2000), was developed to provide practitioners of ergonomics in the healthcare industry with a tool that was sensitive to the tasks, issues and postures that are regularly encountered in the provision of care. This tool identifies various postures and accounts for the load that is handled. An overall score is provided by a series of look-up tables. This tool has yet to be validated, and does not assess the risk of injury through the cumulative effect of repetitive loading in multiple tasks.

Cumulative loading models

Several researchers have proposed that repeated loading of the lumbar spine will lead to low back injury (Sandover 1983, Morrison *et al.* 1997, Marras 2000). Exposure to whole-body vibration has been shown to lead to the development of microfractures of the vertebral endplate (Hansson *et al.* 1987). It is theorized that the healing process for these microfractures will lead to the development of scar tissue on the end plate. The scar tissue, being denser, would impede blood & nutrient flow to the intervertebral disc. The decrease in nutrient flow would lead to negative changes in the properties of the disc. This process would increase the possibility of facet joint pain (reducing disc height increases duration and frequency of contact between facets of neighbouring vertebrae), disc prolapse (the reduction in viscoelastic properties impedes the nucleus pulposus' ability to migrate back to centre of the disc after prolonged flexion of the spine), and altered spinal biomechanics.

Kumar (1990) examined cumulative loads experienced by workers in both their current and previous jobs over the course of their work history. He determined cumulative load by first collecting postural, load, duration and low back pain data reported by the workers for their work tasks in their current jobs. He also collected the same data for each worker's previous jobs. By transcribing the posture and load data into a biomechanical model, Kumar calculated the load for each task at 200ms intervals. These loads were summed together to provide the cumulative load for each task. Both cumulative compressive and shear loads were calculated in this manner. In his report, Kumar reported that the cumulative compression and shear values for male workers who have experienced low back pain was significantly higher than male workers who had not experienced low back pain. He also found that the average duration of work for the pain group at time of pain onset was significantly higher that the mean duration of work for the no pain group. In this sense, Kumar's method provides evidence to show that the longer an individual has worked and has been exposed to compressive (female lumbar and thoracic spine only) and shear (male lumbar and female thoracic and lumbar spine) loading, the greater the likelihood of experiencing low back pain.

There are, however, a number of limitations with Kumar's approach. The values that were calculated for cumulative compression and shear were specific only to the worker sample group that was examined. These data have not been validated against epidemiological data from other groups of workers within or outside of healthcare. Since these compressive and shear loading data have not been validated in a predictive context, they do not provide a threshold limit to be avoided but rather only demonstrate relative risk only for the workers studied. The data collected on tasks, postures and weights were obtained retrospectively, which may present some bias in the data. Lastly, the statistical significance of the differences between workers with pain and those without were specific to the type of force (compression or shear), the section of the spine affected (thoracic or lumbar) and the gender of the worker.

In 1998, a large ergonomic study of the risk factors for low back injury was conducted in an automobile assembly plant to determine the contribution of different personal and workplace variables to the likelihood of reporting low back pain (LBP) among automobile assembly workers (Norman *et al.* 1998). It was a prospective cohort case-control study, where cases were defined as those workers who reported a new episode of LBP at work, and controls were those workers that have not reported LBP at work for at least the last 90 days. Over a two year period, over 250 workers were observed performing their tasks within their jobs. Workplace measures were taken of a range of risk factors during these observations. Videotape data were taken to capture sagittal postures during task performance. Weights of materials were measured by a trained observer, and force data were taken by using a transducer between the worker's hands and the tool used. Where transducer insertion was not practicable in this manner, the worker was asked to replicate the force magnitude and direction on a wall-mounted transducer located next to the workstation. The video and force data were then reviewed to identify the most stressful posture for each task, which was then digitized and used to calculate postural variables (i.e., trunk kinematics) as well as force variables (i.e., spinal compression, spinal shear). The cumulative load factors calculated were the task integral of the peak load value for each measure in each task, the duration of exposure to the respective peak load, and the frequency of task occurrence within the job. Cumulative load factors in this study included cumulative shear force, cumulative moment and cumulative compression force at the L4/L5 lumbar spine level. All peak and cumulative factors were able to distinguish between cases and controls at a statistically significant level ($p<0.05$). The researchers then calculated correlation coefficients for each variable identified in their analysis and found strong relationships within the peak variables and within the cumulative variables, but not across data groups (i.e., peak compression correlated strongly with peak moment and peak shear, but not with cumulative compression). The researchers concluded that the cumulative load data provided different information about relative risk than did the peak loading data. In order to determine the relative risk present in cases and controls for each contributing variable, the researchers calculated odds ratios for each variable. The conservative calculation for odds ratios for the cumulative load variable was 1.4, meaning that there was a 40% greater likelihood of subjects being at risk of reporting LBP for a given increase in cumulative load. While this study provides evidence of the contribution of cumulative loading variables to the likelihood of reporting LBP at work for a specific occupational group, it provides only a relative risk indicator. These indicators do not provide a measure than can be taken out of context and applied to a different occupational group or other tasks; the relative risk for cumulative loads determined in this study applies only to automobile assembly workers from the plant where the data were collected. Just as with Kumar's approach (1990), the values for cumulative loads calculated in this study do not offer a threshold value to be avoided, but only serve to show a difference between groups. In addition, the cumulative compression was not related to any tissue failure model or method of predicting injury. This method of integration has also been shown to over-predict cumulative loading values (Callaghan *et al.* 2001). The researchers did, however, acknowledge that the injury mechanisms for sustained and repetitive loading are likely to be different and that these differences were not accounted for in their research methodology.

Despite limitations within Kumar's approach (1990), it was adopted by Daynard *et al.* (2001) in their examination of various patient handling methods used in a multi-arm intervention in an acute care hospital. The findings of Daynard *et al.* indicated that in many of the tasks performed, both manual and mechanical methods demonstrated high peak compressive loads at L4/L5 without a significant difference in the peak loads between the two methods. Due to the lack of differences in peak loads, the researchers turned their attention to the cumulative loading values. Since the mechanical and assistive techniques required a greater amount of time to complete the task, the cumulative loads were higher when compared to some "safer" mechanical tasks. The authors concluded that these tasks would present greater risk of injury based on the findings of Kumar (1990). However, the authors do not provide a threshold value for cumulative compressive nor cumulative shear loading beyond which risk of injury greatly increases. Without this threshold value, it is not possible to conclude that any individual cumulative loading value is low, moderate or high risk. It is only possible to conclude that risk is likely to be relatively higher in those activities that present with larger cumulative loads. Based on the lack of threshold criteria, it is not possible to categorise any of the cumulative loading values presented by Daynard *et al.* (2001). The conclusions of Daynard and colleagues are contradictory to the literature on the effectiveness of mechanical assistive devices in reducing rates of injury in healthcare workers (Holliday *et al.* 1994, Mughal 2002, Ronald *et al.* 2002, Evanoff *et al.* 2003).

One limitation of the approaches used by Kumar (1990), Norman *et al.* (1998) and Daynard *et al.* (2001) is that cumulative loads were calculated as an integration of lumbar spinal compression over time. This approach assumes that the effect of lifting 1N for 1000 seconds is the same as lifting 1000N for one second.

Given the shortcomings of all the models discussed above, there is considerable benefit to develop an objective model that provides a measure of risk of injury that has its foundations in the mechanisms of low back injury, is transferable across work environments and can provide a measure of risk of low back injury in healthcare workers. While a threshold value would be of benefit and a familiar measure for those working in occupational health and safety, a probability model would provide more flexibility and may produce more meaningful measures for administrators and other non-ergonomists.

Material fatigue model

In order to explain the onset of LBI due to repetitive loading, a material fatigue model has been proposed by a number of researchers (Sandover 1986, Payne 1992, Morrison *et al.* 1997, 1999). This model assumes that the onset of trauma in tissue results from the cumulative exposure to peak loads, and that failure can be defined as a function of the peak load and the number of cycles (or repetitions). This model has its foundations in material fatigue theory (Miner 1945), which describes the ability of a material to tolerate repeated loading.

A number of studies have reported the relationship between repeated loading and fatigue failure of biological tissues (Sandover 1983, Hansson *et al.* 1987, van Dieen & Toussaint 1997, Zioupos *et al.* 2001). Sandover (1983) proposed two mechanisms of fatigue failure regarding cumulative loading in low back disorders: 1) that cumulative axial loading leads to damage to the vertebral end-plate, which affects the nutrition of the intervertebral disc, and 2) that dynamic shear, bending and rotational loading leads to the breakdown of the annular tissues of the intervertebral discs.

Morrison *et al.* (1997, 1999) have used this approach to assess the hazard of LBI in operators of military ground vehicles. Through biomechanical analysis of lumbar joint loading and a fatigue failure model, the researchers proposed a method of LBI risk assessment when military personnel are exposed to repeated mechanical shocks. This fatigue failure approach to LBI has been further developed into a draft international standard for assessment of repeated impact in humans (ISO 2004). A similar approach may be applicable to evaluating the risk of LBI from repetitive spinal loading associated with patient handling. The work of Sandover (1983), Payne (1992) and Morrison *et al.* (1999) serves as the foundation for the model developed in this thesis.

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DESIGN OF THE RESEARCH PROJECT

Hypothesis

Previous research has shown that peak loading and work history are correlated with risk of injury. However, the nature of the relationship between these parameters is not clearly defined. This research project addresses the hypothesis that a model can be created that will predict probability of low back injury based on a function of peak loading of the L4/L5 spinal joint, material properties and occupational exposures over an entire working career.

The model will be developed using parameters determined from the literature and defined by ergonomic assessment of the work tasks performed in residential care. The model parameters will be adjusted to a best fit to the injury data obtained from the employer's injury database. The parameters used in the final model will be compared to those published in the literature. The output of the model (probability of low back injury as a function of work experience) will be compared to data available from actual injury statistics.

Objectives

The overall objectives of this project are first to investigate work design, physical demands, repeated loading and low back injury rates in residential care workers. Secondly, to develop a predictive model that can be used to assess risk of low back injury in this worker population.

Inclusive within the overall objectives are the following specific objectives:

- To establish a profile of the daily work of residential care workers that describes typical tasks performed in the course of work and the associated physical demands and task frequencies;
- To calculate the peak compressive forces at the L4/L5 joint of the lower back during each critical task;
- To develop a model based on fatigue failure for predicting risk of LBI.

This research project is divided into four studies as listed below:

- Study I: Subjective Assessment of Work Tasks and Analysis of Injury Data
- Study II: Biomechanical Modeling of Work Tasks
- Study III: Comparison of Subjective and Objective Measures of Workplace Risk Factors for Low Back Injury

- Study IV: Modeling Cumulative Risk Factors for Predicting Probability of Low Back Injury

The achievement of the objectives will involve analysis of injury records over a five-year period, examination of the tasks and patterns of work currently occurring in six residential care units through focus groups, task analyses in the workplace to confirm methods used to complete work tasks, and subjective evaluation of perceived effort and stress of identified tasks, to be accomplished in Study I. For Study II, biomechanical analyses of critical tasks will be completed to provide compressive forces for each of the typical tasks identified in Study I. Study III will compare the subjective findings from Study I to the objective measures obtained from Study II. In Study IV, a model will be developed for assessment of LBI risk using material fatigue characteristics. Together with data from Study I and II, the performance of this model will be compared with other models currently available in the literature that assess risk of low back injury. Each study will conclude with a summary of the findings and will highlight areas of future research. The entire paper will conclude with a discussion of the limitations of this research.

STUDY I: SUBJECTIVE ASSESSMENT OF WORK TASKS AND ANALYSIS OF INJURY DATA

Abstract

The risk of musculoskeletal injury to residential care workers is well documented in the literature. Historically, residential care has had a higher rate of injury when compared to the entire healthcare industry. Of all injuries, low back injuries occurring during patient handling tasks are the most frequent type of injury sustained by residential care workers.

This study examined historical injury data among residential care workers, as well as perceived levels of stress and exertion reported by direct care givers and perceived contributors of injury in the work environment. Injury data collected over a 5 year period were extracted from an employer's injury database, and filtered to exclude any repeat low back injury to the same worker within the 5 year period. A total of 159 injury records were identified in the 5-year data set, providing a mean annual injury incidence of 33.2 (SD=6.4) and an annual rate of 5.6% per year in a population of 578 workers. This is equivalent to 7.2 low back injuries per 100 FTE. When examined across employment status, it was found that full time workers had significantly higher ages and years of work experience at time of first low back injury when compared to part time and casual workers ($p<0.05$). There were no significant differences in age at time of hire among the 3 groups.

Focus groups consisting of eight volunteer workers were held at six different care units, to obtain subjective data. Each group was asked to develop a list of tasks that they considered to be a part of their daily routine. Each worker was asked to rank the tasks according to level of physical stress on their low back, rate the tasks for perceived exertion at their low back using the Borg

scale, provide typical frequencies for each task during the course of a typical shift, and report perceived contributors of low back injury in the work environment. Results show that the top six tasks according to both mean ranking and rating scores were "dressing in bed", "bowel care", "am/pm care", "stretcher bath", "turning in bed", and "boosting in bed". Although the ranking and rating scores were highly correlated ($r=-0.88$, $p \leq 0.001$), this list order was not wholly consistent between the ranking and rating scores. When compared to a previous study that assessed risk of injury in the same type of care environment, there is a shift from manual transfer tasks to the in-bed tasks as the most significant contributors to injury, indicating successes in addressing risks associated with manual transfer tasks in the healthcare industry in the years between the studies. Perceived contributors of injury include relationships between and within work groups, and between care givers and the resident and their family. Expectations of the family are reported to place pressures on the care givers to rush in the course of providing care, thus increasing their risk of low back injury.

Introduction

In British Columbia, citizens who are very physically dependent and cannot be cared for safely at home are candidates for care at the extended care level, offered within residential care facilities. In residential care, tasks such as distributing medications and wound care are provided by Registered Nurses (RNs); hands-on care such as washing, dressing, feeding and transferring the residents is provided by Resident Care Attendants, Care Aides or Nurse Aides (RCAs).

Low back injury (LBI) is the most common type of work-related injury suffered by workers in British Columbia (BC), accounting for 30% of all injuries reported to the Workers' Compensation Board of British Columbia (2002). In a focus report on work-related injury in healthcare, the Workers' Compensation Board of British Columbia reported that back injuries accounted for 36% of injuries in healthcare during the period of 1994 to 1998, and that 38% of all injuries reported were related to patient handling (WCB of BC 2000). More recent statistics indicate that the prevalence of patient handling injuries remained high through 2001, with 34% of time loss injuries and 41% of all healthcare claims costs in BC associated with patient handling (WCB of BC 2002). When compared to all other industries in BC, healthcare had the highest number of overexertion claims (5,255 reported injuries), the highest number of days lost (412,000) and the greatest short-term disability claims costs ($48 million) in 2001 (WCB of BC 2002). Nurse aides, licensed practical nurses and care aides accounted for 34% of all injury reports in healthcare from 1994 to 1998, the most of all occupational groups. For this same group, back injuries accounted for 52% of all reported injuries related to patient handling (WCB, 2000).

The risk of injury associated with patient-handling tasks has been well documented in the literature (Jensen 1990, Garg *et al.* 1992, Owen *et al.* 1992, Holliday *et al.* 1994, Yassi *et al.* 1995, Engkvist *et al.* 1998, Marras *et al.* 1999, Bewick and Gardner 2000, Lynch and Freund 2000). Different methods have been used to determine the level of risk in the healthcare work environment (Kumar 1990, Garg *et al.* 1991a, 1991b, Steinbrecher 1994, Laflin and Aji 1995). A few studies have examined risks for low back injury in residential care work (Garg *et al.* 1992, Owen *et al.* 1992). Garg *et al.* (1992) found that tasks involving the transfer of patients between the bed, chair and toilet were perceived to be the most difficult to perform and were associated with the greatest level of risk of low back injury. However, given the progress in injury-reduction initiatives in healthcare over the past 10 years, it is unlikely that the task analysis performed in 1992 would be directly applicable to the current work techniques and environment present today. Current information on the design and requirements of the work task is necessary for any model that would even attempt to assess risk of low back injury in a workforce.

This study involves the participation of a total of 48 volunteer workers over six focus groups held at six different residential care units. Using data collected from these focus groups, this study examines subjective measures of physical stress and effort related to the low back for RCAs working in residential or extended care. This study also analyses injury data from a large healthcare employer to determine rates of low back injury.

Methods

Setting

Fraser Health Authority is a healthcare administration in British Columbia, Canada with 13 facilities and numerous community offices providing acute, residential and community care services to 1.4 million citizens.

The protocol used in this study was reviewed by and received approval from Simon Fraser University's Research Ethics Board.

Injury Data

Injury data from a five-year period, 1997 to 2001, were extracted for five facilities from the healthcare employer's injury record database and placed into a spreadsheet (Microsoft® Excel 2002). Only WCB-accepted claims were extracted from the database. WCB-accepted claims were selected as the best available data since they are independently diagnosed and confirmed, whereas low back pain is a subjective measure that will vary from worker to worker. They injury data included name of the worker, occupation, employment status (full time, part time, casual), division, department, date of the injury/incident, body part injured, nature of the injury, and description of the incident. Further data reduction is described in the results section.

Focus Group Data

A total of six focus groups were organized at six different residential care units across Fraser Health. RCAs were invited to voluntarily participate in a focus group for their unit; eight (8) participants were included per focus group. All subjects were provided with written project information and provided voluntary written informed consent prior to participating in the study.

Workers in each focus group were first asked, as a group, to develop a list of the most difficult resident care tasks that are performed on a regular basis. Each focus group was facilitated by the investigator in order to ensure consistent terminology for tasks across all focus groups in the study. Once this list was developed, the workers were asked to complete, independently of the others in the focus group, three paper exercises using the list of tasks they had developed.

The first exercise involved ranking the tasks from most to least stressful for their lower back. Each worker was provided a copy of the list of tasks developed in the first part of the focus group. Each worker was asked to identify the most difficult task on the list, and give that task a ranking of "1". They were then asked to identify the next most difficult task and give that task a ranking of "2", and so on until every task on the list was given a rank value. Where workers were unable to rank two tasks differently, they were allowed to rank them at equal positions and appropriate corrections were made to the subsequent rank values.

The second exercise required the workers to rate each task for perceived physical exertion on their lower back using the Borg (1990) scale. The Borg (1990) scale was originally developed to provide a subjective scale that was reflective of the exertion levels experienced by the subjects performing physically demanding work. Borg created a non-linear scale with descriptive anchors along parts of the scale that reflected the level of exertion of that particular value (see Figure 5). This scale was displayed on an overhead projector during this exercise. Each subject was provided a new sheet with the same list of tasks as in the previous exercise. They were asked refer to the scale as they reviewed each task on the list and give it a rating of perceived exertion that they experience at their low back during a typical performance of that task.

Fraser Health
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Rate of Perceived Exertion Scale[1]

Using the following scale, **rate each task** on the Task Worksheet for your perceived exertion on **your lower back.**

6	No Exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

[1] Borg, G. (1990). Psychophysical scaling with applications in physical work and the perception of exertion. *Scand J Work Environ Health, 16*(Suppl 1), 55-58

Rate of Perceived Exertion Scale (Borg 1990) last saved on: 24 Oct 03 *Page 1 of 1*

Figure 5. Rating scale used during focus group data collection

In the third exercise, each member of the focus group was asked to report the frequency that they would perform these tasks during a typical 8-

hour shift. The workers were provided with a third sheet with the tasks listed, with space to indicate the frequency of task performance. When tasks occurred on a frequency of less than once per shift, the workers were asked to indicate an appropriate frequency on the form (i.e., once per week, once per month, etc...). This value was then converted into a "per shift" value based on number of shifts per week or month, as appropriate.

After the completion of the three exercises, the subjects were engaged in a facilitated discussion about the perceived causes of low back injury in their work environment. Their comments were transcribed onto a computer during the discussions by an assistant or the investigator.

Analysis

Injury Data

The data were filtered at a number of levels. These levels provided the total number of reports for all departments, only nursing departments, all residential care nursing and only incidents that occurred to residential care attendants (RCAs). A count was performed at each level to obtain the number of musculoskeletal injuries. At the RCA level, counts of low back injury were also performed. The final filter resulted in a data set that included only those records that were first-time low back injuries to RCAs.

For the final data set, date of birth and date of hire were obtained for each first-time low back injury and assigned to the appropriate injury record. Using the available data for each incident, new variables were calculated for each injury record: age at time of injury and years of work experience at time of injury.

Selected variables were then moved into a statistical software program for further analysis (SPSS 12.0, SPSS Inc., 2003). These variables included employment status (full-time, part-time or casual), age on date of hire, age at time of first low back injury, and years of work experience at time of first low back injury. Descriptive data were calculated to provide mean and standard deviation values for each of the variables across employment status groups. One-way analysis of variance (ANOVA) was performed for each variable to examine for differences across employment status groups. Statistical significance for each test was set *a priori* at $\alpha = 0.01$. Post-hoc analyses using Tukey's Honestly Significant Difference were performed for each of the continuous variables to identify employment groups that were significantly different from each other at the $p<0.05$ level.

Focus Group Data

All numerical responses collected during the focus groups were entered into a statistical software program (SPSS v12.0) for analysis. Individual data from the exercises were excluded if the responses were illegible.

Descriptive statistics were calculated to provide means and standard deviations values for all tasks in each exercise. Analyses of variance (ANOVAs) were conducted for each task and exercise (23 tasks x 3 exercises) to examine for a main effect of resident care unit. Due to the number of tests, there were insufficient degrees of freedom remaining in the analyses to perform a single ANOVA for each exercise. To reduce the probability of Type II errors in the analysis, the significance level for each ANOVA was set at 0.01. Pearson correlation coefficients were calculated across all three subjective variables to examine inter-relationships among the variables.

Comments recorded during the focus groups were collected and examined to identify consistent issues or themes in perceived causes of injury. The data were then summarized in point-form in a table.

Results

Injury Data

Thirty-four records were excluded from analysis due to workers having left the organization at the time of analysis. Their date of birth was no longer accessible within the employer's electronic system, hence their data could not be used in the determination of age and years of work experience variables.

Table 3 provides frequency statistics obtained from the data reduction process used in the analysis of injury data. Table 4 provides specific values of relevance to the current study.

Table 3. Frequency statistics from historical injury data (1997-2001)

Source of Injury Reports	all claims	# MSIs	%MSIs	# LBIs	% LBIs of all claims	% LBI of MSI claims only
All departments	5289	2541	48%			
All nursing care only	2992	1487	50%			
RCAs only in residential care	837	537	64%	220	26%	41%
RCA LBIs after removing all repeated occurrences	n/a	n/a	n/a	159	11%	22%

Table 4. Interpretive proportions from historical injury data

Percent of ...	Proportion
all claims that were "Nursing" division	57%
RCA-specific claims of all reported claims	28%
RCA injury claims that were MSIs	64%
RCA injury claims that were LBIs	26%
RCA MSIs that were LBIs	41%
RCA LBIs that are 1st time	72%

Results from Tables 3 and 4 show that 57% of all injury reports that were recorded within the five-year period occurred in nursing environments, and half of these reports were musculoskeletal injuries. Residential care workers reported 28% of all injuries reported in the organization during the five-period. The majority (64%) of the injuries occurring to RCAs were musculoskeletal injuries, with low back injuries accounting for more than one-quarter (26%) all injuries reported by RCAs and 41% of all musculoskeletal injuries were low back injuries.

The mean age at date of hire, age at first low back injury and years of work experience at first low back injury, together with standard deviations and number of data points in each group, are shown in Table 5 and Figures 6-8 for each employment group.

Table 5. Descriptive statistics for historical injury data

Variable	Occupational Status	Mean	Std. Deviation	N
Age on Date of Hire	Full Time	32.7	8.0	56
	Part Time	34.2	8.3	39
	Casual	34.4	7.8	36
	Total	33.6	8.0	131
Age on Date of Injury	Full Time	47.4	8.5	56
	Part Time	41.8	8.1	39
	Casual	39.4	7.8	36
	Total	43.5	8.8	131
Years of Work Experience	Full Time	14.7	5.3	56
	Part Time	7.5	4.7	39
	Casual	5.0	5.4	36
	Total	9.9	6.7	131

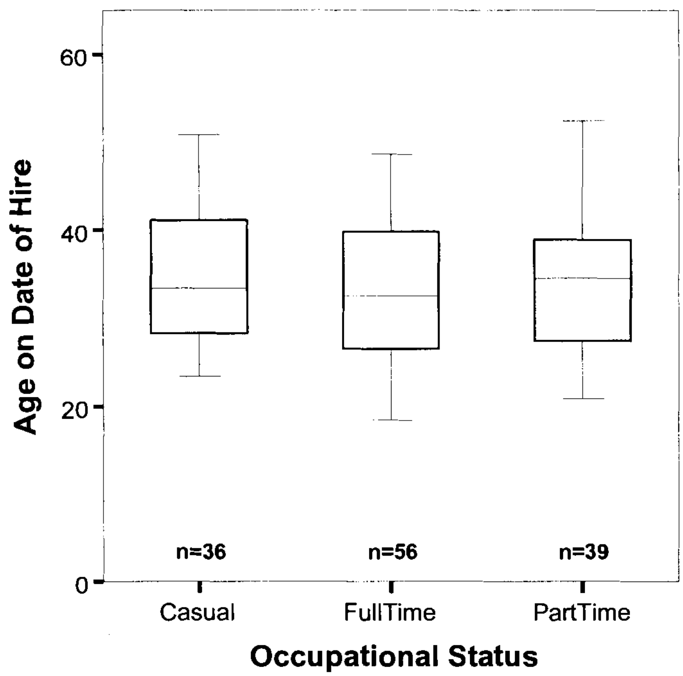

Figure 6. Mean, SD and range of age at date of hire

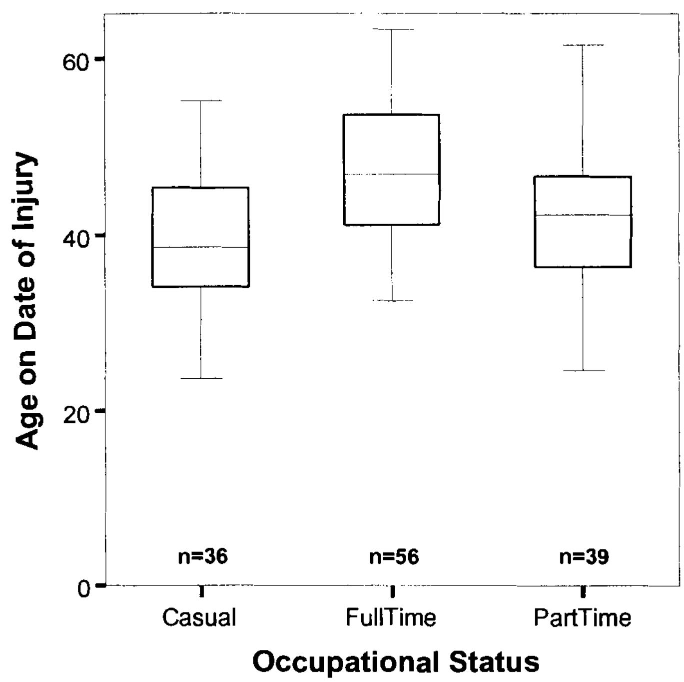

Figure 7. Mean, SD and range of age at time of low back injury

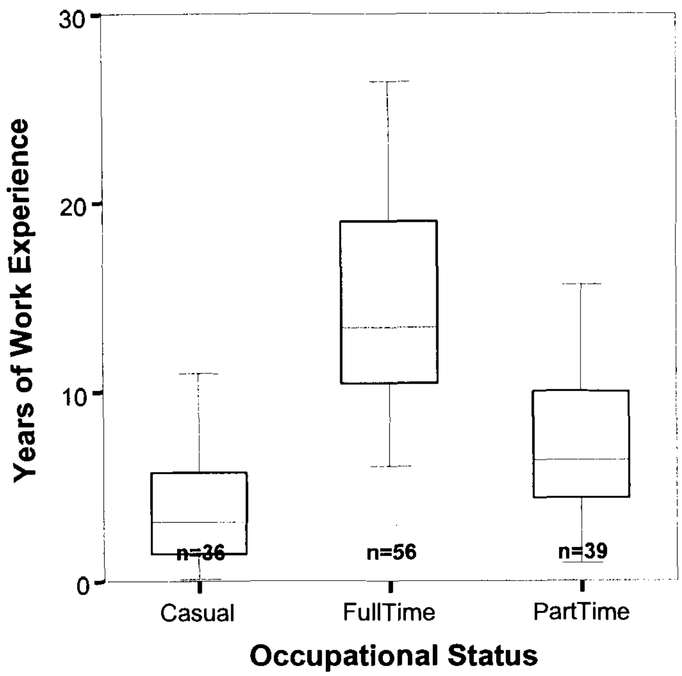

Figure 8. Mean, SD and range of years of work experience at time of low back injury

The effects of employment status on age at date of hire, age at time of LBI and years of work experience at time of LBI are shown in Table 6. There was a main effect for both age at time of injury and years of work experience at time of injury ($p<0.001$). There is no difference, however, in the age at the time when the workers were hired by the employer (34.3 years versus 33.4 and 34.1 years, $p=0.51$).

Table 6. ANOVA table of injury data by employment status

		Sum of Squares	df	Mean Square	F	Sig.
Years of Work Experience	Between Groups	2367.664	2	1183.832	44.739	.000
	Within Groups	3387.010	128	26.461		
	Total	5754.674	130			
Age on Date of Injury	Between Groups	1551.586	2	775.793	11.592	.000
	Within Groups	8566.661	128	66.927		
	Total	10118.247	130			
Age on Date of Hire	Between Groups	88.032	2	44.016	.682	.507
	Within Groups	8256.329	128	64.503		
	Total	8344.361	130			

Table 7. Post-hoc analysis of age at date of injury grouped by employment status

Employment Status	N	Subset for alpha = .05	
		1	2
Casual	36	39.41	
Part-Time	39	41.76	
Full-Time	56		47.354

Table 8. Post-hoc analysis of years of work experience grouped by employment status

Employment Status	N	Subset for alpha = .05	
		1	2
Casual	36	4.98	
Part-Time	39	7.51	
Full-Time	56		14.67

Results of post-hoc analyses, shown in Tables 7 and 8, reveal statistically significant differences between Full Time workers and the other two groups (Casual and Part Time workers) with respect to age at time of injury (47.8 years versus 39.2 and 41.8 years, $p<0.05$) and years of work experience prior to first low back injury (14.4 years versus 5.1 and 7.4 years, $p<0.05$).

Data from the employer's Human Resources department indicate that there were 691 workers employed within all of the departments included within this study.

Table 9. Annual incidence of first-time low back injury

year	# 1st LBIs	rate/100 FTE
1997	34	7.6
1998	32	7.1
1999	26	5.8
2000	42	9.4
2001	27	6.0
Average	*32.2 (SD 6.4)*	*7.2 (SD 1.4)*

Table 9 indicates that the average number of first-time low back injuries that can be expected to occur each year in this worker population is approximately 32 (SD=6.4). This translates to an annual injury incidence rate of 5.6% over 578 workers (and 7.2 per 100 FTE). After five years, approximately 28% of workers in this occupational group would be expected to have experienced a low back injury, and in less than 20 years of working, all workers are expected to have experienced at least one low back injury.

In comparison to industry data, the provincial average annual injury rate for residential care, which includes all types of injuries, was 8.9 per 100 FTE (Full-Time Equivalents) in 1998. Using data from Table 9, the injury rate for this employer for low back injuries alone are 7.2 per 100 FTE. This rate and the annual incidence rate represent a serious low back injury problem for this occupation.

Focus Group Data

A total of 48 subjects participated in this study. Subject profile data are summarized in Table 10.

Table 10. Subject Profile Summary

	Gender	Mean	N	SD	Minimum	Maximum
Height (cm)	Female	162.3	43	5.2	149.9	174.0
	Male	185.3	2	7.4	180.0	190.5
	Total	163.3	45	7.0	149.9	190.5
Mass (kg)	Female	71.1	43	12.9	50.0	111.7
	Male	90.8	2	6.4	86.3	95.3
	Total	72.0	45	13.3	50.0	111.7

A list of all the tasks discussed in the focus groups, together with their descriptions, is provided in Table 11.

Table 11. Task list and descriptions

Task	Task Description
Dressing in bed	Removing and applying clothing while the resident is lying in bed.
Bowel care	Providing an enema treatment to the resident.
Am/pm care	Cleaning of the face, neck, trunk, arms, hands, pelvic and peri areas while the resident is in bed. Usually performed using facecloths, towels and a basin of water with spray soap.
Stretcher bath	Bathing a resident while they lie supine on a vinyl-covered pad on a stretcher. Usually performed using facecloths, towels, a water sprayer and spray soap.
Turning in bed	Turning a resident onto their side.
Boosting in bed	Moving a patient up towards the head of the bed when they have slid down the length of the bed.
Use of lifter	Use of a mechanical patient lift device. A completely depended method that places the resident in a sling which is attached to the lift. The lift will then raise and allow the lift and resident to be moved to a new destination. This device can be used to and from both sitting and lying positions.
Showering	Washing a resident in an adapted shower stall while the resident is sitting on a shower chair
Lying to sitting	Repositioning a resident from lying supine in bed to sitting on the edge of the bed.
Manual lift from floor	Lifting a resident off the floor using physical effort only (no mechanical lift used) **Note: not common nor endorsed by the management of any unit in this organization, unless in an emergency or other identified situation.*
Bathing in tub	Washing a resident while they are in a tub.
Positioning in bed	Physically adjusting the position of the resident's body (head, arms, legs, and/or pelvis). Once the resident's position has been modified, that position is maintained by the insertion of padded bolsters or pillows.
Use of stander	Use of a mechanical sit-stand device (A semi-dependent method that raises the resident from a sitting position to a semi-sitting position for the purposes of moving them to another seated location)
Toileting	Transferring a resident to the toilet in the washroom.
Reposition in wheelchair	Modifying the seated position of a resident in a wheelchair to allow for proper sitting posture of the resident. Usually performed immediately following a transfer to a wheelchair, and throughout the day as necessary

Task	Task Description
Bed bath	Washing the entire body of the resident. Includes all aspects of am/pm care with the addition of washing the hair, legs and feet while the resident is lying in bed. Generally, this method requires more water, soap and towels to complete.
1-P transfer	A transfer task performed to move a resident from one sitting location to another sitting location, usually adjacent to each other. Performed using only one worker, usually indicating that the resident has some physical ability to assist in the transfer task.
2-P transfer	Same as 1-P transfer, but the resident is either less able to assist, heavier, or has other functional difficulties that require a second worker to assist with the transfer.
Mechanical lift from floor	Use of a mechanical patient lifter to lift a resident that has fallen to the floor.
Sitting to standing	The worker assists a resident to standing from sitting, after which the resident has the ability to mobilize themselves.
Washing in bathroom	Cleaning the peri-area of a resident after they have used the washroom.
Assisted walking	Assisting a resident with walking from one location to another.
Feeding	Assisting with or feeding food to the resident during meal times.

The subjective data obtained from the three paper exercises are presented in Table 12. The mean, standard deviation, and number of subjects (N) reporting are provided for the ranking, rating and frequency of each task. Tasks which had a low number of subjects were not identified by all focus groups.

Table 12. Mean values reported for each exercise

Task	Perceived Stress (Rank)			Perceived Effort (Rate)			Task Frequency		
	Mean	SD	N	Mean	SD	N	Mean	SD	N
Dressing in bed	3.7	3.8	47	16.3	2.9	48	8.3	3.6	48
Bowel care	4.0	2.0	5	15.0	1.8	6	2.1	1.5	8
Am/pm care	4.2	3.9	46	15.8	2.7	45	7.0	2.4	48
Stretcher bath	6.0	3.3	34	15.8	3.3	35	1.1	1.7	40
Turning in bed	6.2	3.7	47	15.4	2.7	48	14.3	9.1	48
Boosting in bed	6.6	3.7	47	14.8	2.9	48	12.6	7.4	48
Use of lifter	7.3	4.2	46	14.2	2.6	48	7.2	6.9	46
Lying to sitting	7.6	4.0	47	14.5	3.0	48	6.2	4.7	48
Showering	7.6	3.9	9	14.7	3.5	12	0.8	1.1	16
Bathing in tub	7.9	3.7	42	12.9	3.1	43	1.1	1.5	48
Manual lift from floor	7.9	3.8	8	13.9	1.2	8	0.3	0.2	8
Positioning in bed	8.5	4.9	23	14.2	2.4	24	14.0	8.5	24
Use of stander	8.6	4.1	47	13.9	2.7	48	4.1	3.6	48
Reposition in wheelchair	9.2	4.5	39	14.4	3.7	40	5.5	3.5	40
Toileting	9.2	4.2	16	12.7	1.1	16	6.0	3.5	16
Bed bath	9.3	3.4	36	14.5	2.9	37	0.8	1.9	40
1-P transfer	9.5	4.0	47	12.6	2.5	48	4.4	3.8	48
2-P transfer	10.1	3.9	23	12.7	3.0	24	4.0	3.8	24
Mechanical lift from floor	10.2	4.1	8	13.1	2.2	8	0.3	0.3	8
Sitting to standing	10.9	3.3	23	13.0	2.6	24	5.1	3.2	24
Washing in bathroom	11.4	2.6	8	13.1	1.4	8	4.2	4.6	8
Assisted walking	11.8	4.2	31	10.4	2.1	31	1.8	1.9	30
Feeding	13.9	4.4	31	10.5	2.6	32	9.2	6.1	32

The mean and standard deviation of the ranking of each task for perceived stress to the low back is presented in Figure 9 according to rank order.

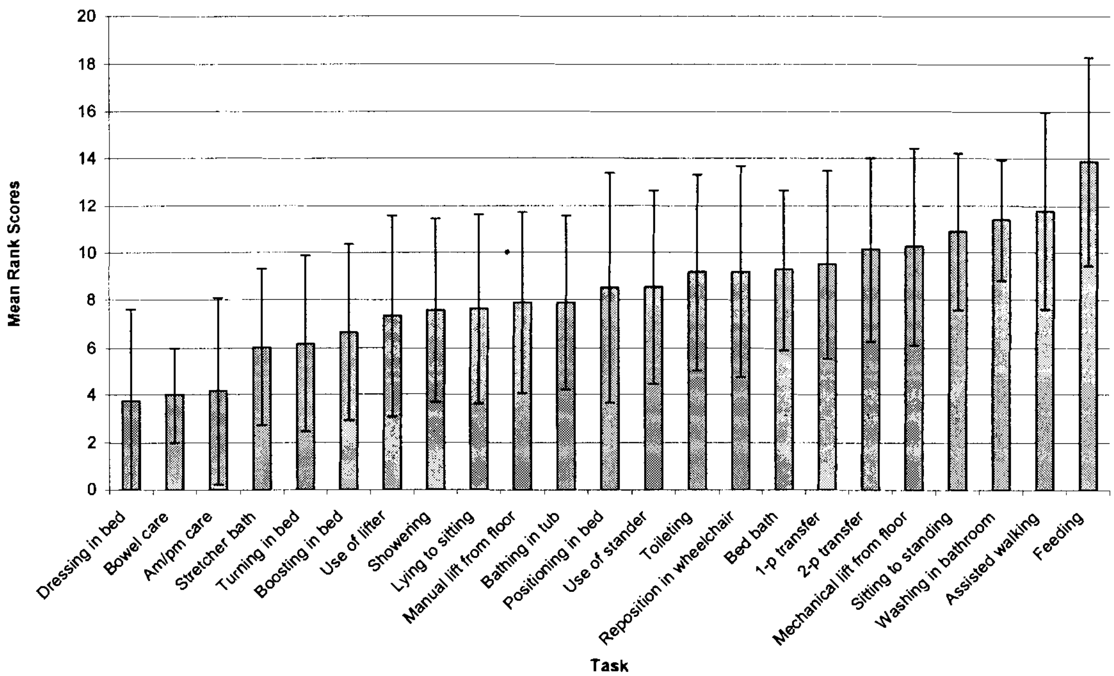

Figure 9. Mean reported ranking scores

The mean and standard deviation of the rating of each task for perceived effort to the low back is presented in Figure 10 according to Borg scale rating.

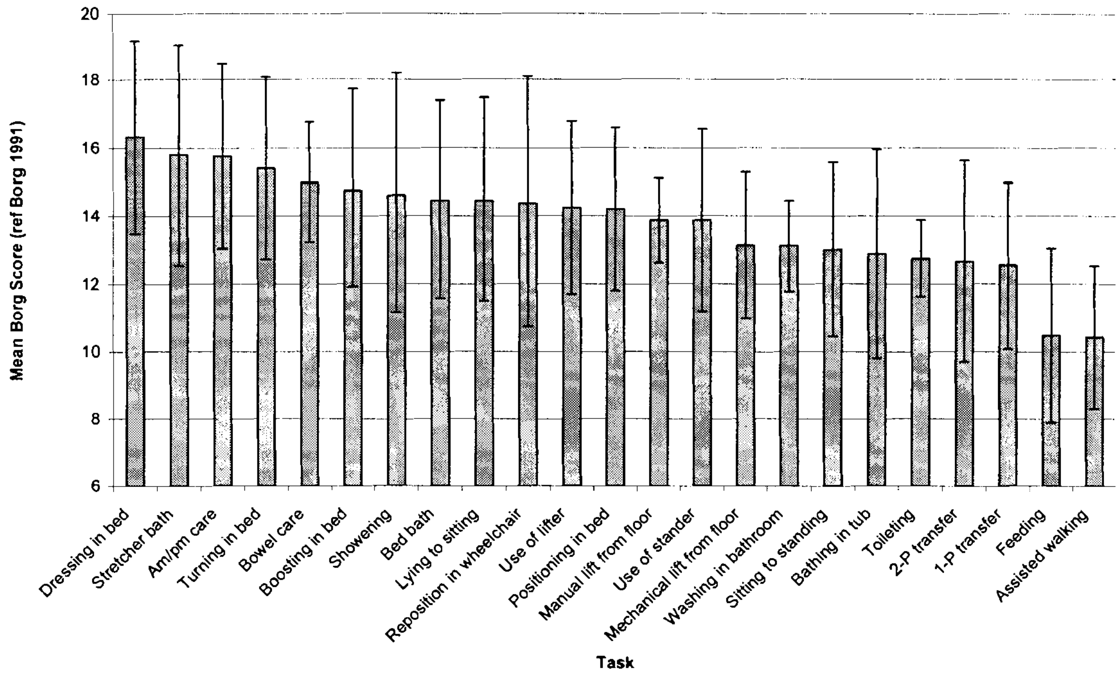

Figure 10. Mean reported rating scores

Table 13 shows the RPE scores for each task as well as the anchors from the Borg Scale (1990). The anchors within the Borg scale that were relevant to the data obtained in this study were "Very Light" at 9, "Light" at 11, "Somewhat Hard" at 13, "Hard" at 15, and "Very Hard" at 17.

Table 13. Mean rating scores for each task

Task	Mean Rating score	Scale	Anchor
		20	Maximal Exertion
		19	Extremely Hard
		18	
		17	Very Hard
Dressing in bed	16.3		
Stretcher bath	15.8		
Am/pm care	15.8		
Turning in bed	15.4		
Bowel care	15.0	15	Hard
Boosting in bed	14.8		
Showering	14.7		
Bed bath	14.5		
Lying to sitting	14.5		
Reposition in wheelchair	14.4		
Use of lifter	14.3		
Positioning in bed	14.2		
		14	
Manual lift from floor	13.9		
Use of stander	13.9		
Mechanical lift from floor	13.1		
Washing in bathroom	13.1		
Sitting to standing	13.0	13	Somewhat Hard
Bathing in tub	12.9		
Toileting	12.8		
2-P transfer	12.7		
1-P transfer	12.6		
		12	
		11	Light
Feeding	10.5		
Assisted walking	10.4		
		10	
		9	Very Light
		8	Extremely Light
		7	
		6	No Exertion at all

As shown in Table 13, the mean rating scores for all tasks fell above the anchor of "Very Light" and below the anchor of "Very Hard". Of the 23 tasks analysed in this study, 74% of the tasks were rated at or above "Somewhat Hard", and 26% were rated "Hard" or higher. Five of the top six rated tasks were rated at and above "Hard" with the highest rating of 16.3 given to "dressing in bed". The two manual transfer tasks of 1-person transfer and 2-person transfer obtained mean rating scores only above feeding and assisted walking. Only these two tasks, "feeding" and "assisted walking", were rated below "Light".

The ranking and rating scores obtained in this study indicate that in-bed positioning and handling tasks are perceived to have the greatest risk of low back injury to the workers.

The mean and standard deviation of the task frequencies per shift are presented in Figure 11 in descending order.

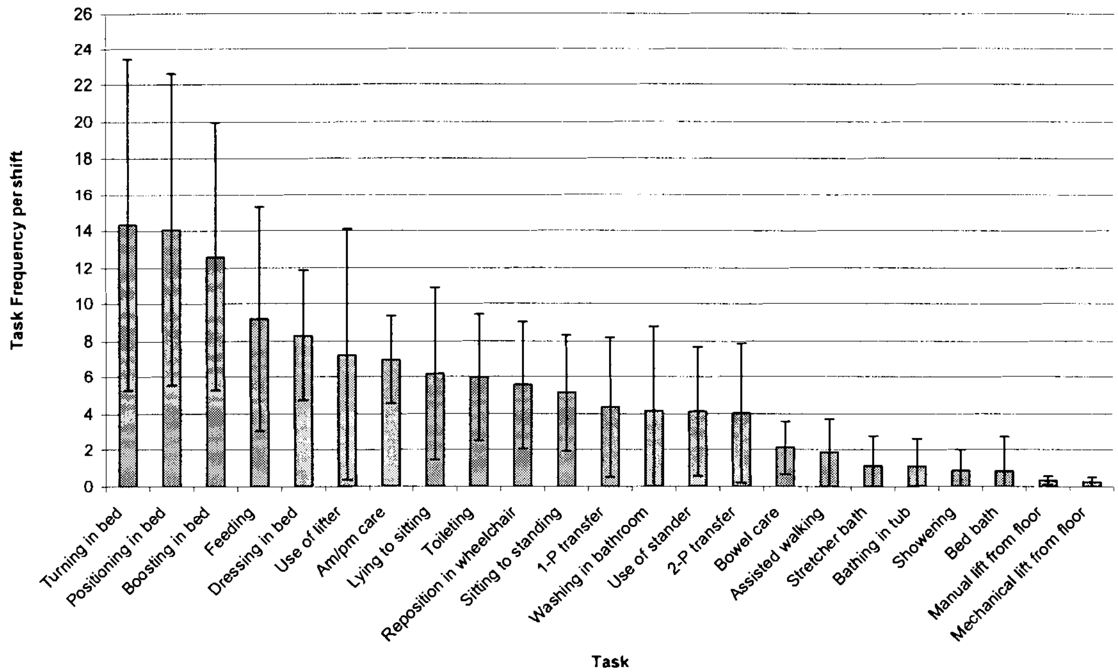

Figure 11. Mean reported task frequencies

Table 14 shows the results of the analysis to identify differences in subjective responses of ranking rating and frequency across care units. The p-values are provided for each ANOVA.

Table 14. Summary of ANOVA p-values across study units

Task	Rank	Rate	Frequency
Dressing in bed	0.836	0.026	*0.001*
Bowel care†	–	–	–
Am/pm care	0.487	0.173	0.117
Stretcher bath	0.202	*0.004*	*0.008*
Turning in bed	*0.008*	*0.001*	0.412
Boosting in bed	0.056	0.019	0.027
Use of lifter	0.033	*0.003*	*0.001*
Showering‡	0.458	0.196	0.445
Lying to sitting	0.478	0.471	0.108
Manual lift from floor†	–	–	–
Bathing in tub	0.423	0.211	0.717
Positioning in bed	0.400	0.542	0.341
Use of stander	*0.006*	0.176	0.279
Toileting‡	0.042	0.672	0.348
Reposition in wheelchair	0.582	0.014	0.017
Bed bath	0.079	0.205	0.682
1-P transfer	0.570	0.095	0.700
2-P transfer	0.126	0.322	0.525
Mechanical lift from floor†	–	–	–
Sitting to standing	0.594	0.075	0.579
Washing in bathroom†	–	–	–
Assisted walking	*0.009*	0.504	0.242
Feeding	0.360	0.301	0.192

Italics in the table indicates significance values of $p<0.01$

† - *indicates only one unit reported data on the task*

‡ - *indicates only two units reported data on the task*

There was only one unit that provided significantly lower ranking positions and lower rating scores for the use of the lifter, and this unit recently acquired the use of ceiling lifts. It is likely that this departure from the other units may be a result of the lower use of the devices; if the floor lifts are no longer used very often, they may not be perceived to be a substantial problem. With "stretcher bath", the facility that stood out had a bath team which is a dedicated position that has workers that perform only resident baths. The majority (five out of eight) of workers were unable to provide rating scores due to the fact that they did not perform the task; however, their data were counted when the frequency values were tabulated. The remaining significant differences cannot be explained with any accuracy based on the focus group and task analysis data collected during this study.

Table 15. Pearson correlation table for subjective variables

		Rank	Rate	Task Frequency
Rank	Pearson Correlation	1		
	Sig. (2-tailed)	.		
	N	23		
Rate	Pearson Correlation	-.884(**)	1	
	Sig. (2-tailed)	.000	.	
	N	23	23	
Task Frequency	Pearson Correlation	-.144	.189	1
	Sig. (2-tailed)	.513	.388	.
	N	23	23	23

**Correlation is significant at the 0.01 level (2-tailed).

The Pearson correlation coefficient between the Ranking and Rating scores was -0.884 ($p<0.01$), as shown in Table 15. The correlations between Ranking & Frequency and between Rating & Frequency were not significant.

Perceived Causes of Low Back Injury

When asked about the contributory factors for injury in the workplace, the workers identified a number of issues. These findings are summarized in Table 16.

Table 16. Summary of reported contributors to risk of low back injury

Reported risk factor group	Issues within each factor
Rushing	Pressure from family members, pressure from management, not wanting to leave work for next shift (increasing their workload)
Working with co-workers	Taking co-worker away from their tasks, concerns as being seen as lazy by co-workers, peer pressure, perception of role of rehabilitation services
Adaptive clothing	Family's refusal to adapt clothing
Resident factors	Aggressive or resistive behaviour, contractures

There is a concern in most units involved in this study that the RCAs are rushing to ensure that all tasks are completed in time, and that residents are up for the day as soon as possible. The focus groups listed a number of factors that contribute to the feeling of being rushed, including pressure from the residents' family members, pressure from the residents themselves, perceived expectations from management, concern for leaving extra work for the next shift to complete and fear of being seen as lazy by their peers if they fail to complete all their tasks. Factors that exacerbate the issue of rushing include exercise sessions arranged by rehabilitation therapy services, schedule of meal delivery, and the scheduled activities that are arranged for selected residents during the morning (i.e., a bus excursion, church sessions, recreational activities, holiday/seasonal activities).

Some workers from selected study units reported communication difficulties related to the determination of the appropriate method of transfer for residents. The method indicated in the resident's chart and at their bedside is usually determined by therapy staff (physiotherapy and/or occupational therapy). The assessment is usually based on a single visit with the resident. The resident care workers are then required to follow the assessed procedure as indicated in the documentation. Some RCA staff report inconsistencies in the method of transfer indicated by therapy staff and the "most appropriate" method for the resident. Some RCAs identified concerns that an assessment based on a relatively brief visit by therapy staff may not have been sufficient to adequately capture the behavioural issues (i.e., resistive or aggressive behaviour) that contribute to the risks of performing patient handling tasks. In addition, the time available to perform the assessments are reported to take anywhere from 15 to 45 minutes, which is considerably longer than the time available to residential care workers to perform the same task. Given the same length of time, RCAs report, they too would be able to obtain cooperative behaviour from the residents. However, with a range of six to ten residents assigned to each RCA, the workers report limited time to address some of the behavioural issues present in most residential care environments.

Relating personal experiences from instructional sessions for new employees, it has been reported that new workers are placed under a great deal of pressure to adapt to the "way it's done" on their new unit, as defined by the more experienced employees. This issue of work culture has not been examined in great detail in the context of safe work practices in a healthcare environment. This type of peer pressure is useful to examine, considering the resources allocated to the training and education of new employees, only to have practice changed once employed on a care unit.

Frequently mentioned by the RCAs was the difficulty in working with some of their co-workers on the unit. Reasons for these difficulties include the lack of the consistency of help offered by their co-workers, a concern of appearing lazy to the other workers who do not ask for help and a concern that they may inconvenience their co-worker by taking them away from the tasks that they are responsible for completing.

Many of the in-bed tasks involve the application or removal of the residents' clothing. Some dependent (low-functioning) residents have obtained adaptive clothing or had their own clothes modified to make them easier for the caregiver to apply and remove. These types of clothing are designed for their ease in application and removal for dependent individuals while maintaining their appearance so that the modifications to the clothing are not easily identifiable once appropriately prepared for the day. Examples of adaptive clothing include split-back pants and wheelchair dresses. These modified articles of clothing also make other tasks easier to perform, such as toileting from a wheelchair. Some residents' families, however, do not see this type of clothing in a positive light and present barriers to its acquisition or the modification of their family member's clothing. Accessibility to the resources required to make the modifications was identified as another barrier to having adaptive clothing available for some residents. There may not be someone on the unit who is able to make the modifications, or the costs involved in sending clothing out for modifications are not a part of the department's operating budget.

Resident-specific factors are also cited as causes for low back injury in the residential care environment. These include physical conditions such as contractures, and behavioural or cognitive conditions such as aggressive/violent behaviour or resistive behaviour, or dementia. These conditions and behaviours increase the level of effort and difficulty experienced while performing most hands-on care tasks such as "am/pm care", "bed baths", "dressing", "turning in bed" and "boosting in bed".

Discussion

The focus group data reveal that subjective measures of perceived stress on the low back and perceived exertion at the low back are closely related. When applied across all 23 tasks analysed in this study, these two subjective measures indicate high levels of perceived risk associated with in-bed care tasks performed in residential care. The top six tasks, according to the subjective measures, are "dressing in bed", "bowel care", "am/pm care", "stretcher bath", "turning in bed", and "boosting in bed". These tasks often involve the hands-on care of residents, often requiring turning them or moving them within their bed, and place the worker in close proximity to the resident.

Injury data

The injury data analysis indicated an annual rate of first-time LBIs of 32.2 per year over five calendar years. This number is reflective of the number of claims that are accepted by the workplace insurance board as low back injury. Out of a worker population of 578, this translates to an approximate rate of 5.6% per year. If this rate is extrapolated, 28% of all workers will have experienced a LBI within five years of beginning their working career in residential care. For this worker population, this amounts to 161 workers.

Further analysis of historical injury data revealed significant differences in the age and years of work experience at time of first low back injury between the full time workers and the part time and casual workers. These differences among employment groups may be present due to the history of the database from which the data were extracted. The database began data collection only in 1992; prior to this, injury records were kept in paper files. Given the longer duration of employment for full time workers (by approximately seven years), it is possible that the database did not capture their first low back injury. It is therefore conceivable that the actual age at time of injury and years of work experience for full time workers are closer to the averages for the other two groups. Without more extensive historical data, this explanation is speculation. However, given that the injury data set was taken from a five year period, there is a higher confidence in the injury data for those individuals that experienced their first low back injury in the first five years of their employment.

Another possible explanation for the difference in age at time of injury is the phenomenon of survivorship in the worker population. Most, if not all of the workers begin their career with the employer as a casual employee, without any confirmed shifts. They may remain as casual employees for some time, with many casual workers leaving the organization before entering a permanent position, some of them due to injury. However, as permanent employees (part time and full time status) leave the organization, surviving casual employees enter the available permanent positions. This may explain the higher age at time of low back injury for full time workers.

Focus Group Data

The first six tasks on the list of tasks in Table 12 are in-bed patient-handling tasks. These data indicate that it is no longer the lifting and transferring tasks that are of most concern to the RCAs in this study, but it is the in-bed positioning and handling tasks. During observations on the study units, no instances of manual lifting and carrying of clients from the one location to another were observed. All manual transfer tasks were performed with residents that had functional abilities and were weight bearing; all residents that did not have the functional abilities to assist with manual transfers were transferred using a mechanical patient handling device (a mechanical lifter or stander). In this manner, lifts and transfer tasks have been addressed to ensure the minimization of risks associated with patient handling tasks. The tasks that remain to be addressed are the in-bed tasks (i.e., boosting, turning, dressing, bed bathing).

This presents challenges to any injury prevention initiative that target these tasks, as it may be difficult to design an engineering control to reduce the physical effort required to wash under a resident's arm while in bed. Other issues, discussed below, may offer some reduction in risk through management of risk factors, such as managing aggressive or resistive behaviour.

"Use of lifter" was still ranked near the top of the list according to the subjective measures. Based on discussions with the focus group participants, their concerns lie in the difficulty required in manoeuvring the lifts once the resident has been lifted.

The high correlation between the ranking and rating scores would indicate that workers perceive "high level of physical stress" on a body part and "physical exertion" of a body part in much the same light. During a risk assessment, therefore, it may not be necessary to use both metrics in order to obtain a list of tasks that the workers feel present difficulties to them. During the focus groups, it was more difficult for workers to rank order the tasks than it was to provide a rated value for each task.

Assuming that the ranking or rating scores provide a clear picture of perceived risk on the work unit, the poor correlation values between these scores and task frequency indicate that high frequency tasks may not necessarily be the best tasks to target for ergonomic intervention. Tasks that occur frequently need to be examined for other risk factors. It may be sufficient to obtain subjective perceptions of risk levels (stresses or exertions) as measures to assist in the prioritization of tasks in need of intervention.

Perceived Causes of Low Back Injury

Rushing appears to be a common concern to most participant groups in this study. There is a possibility of an increase in errors in the performance of work tasks when individuals are placed under pressure to complete tasks within a specified time period. The workers reported that they are more likely to take shortcuts when they are feeling rushed to complete their work tasks. This also highlights the issue of quality of care. The concerns surrounding rushing are not addressed within this study; however given it's prevalence across study groups, it warrants closer examination to determine the prevalence of the problem in the work environment and its contribution to risk of injury and quality of care.

The issue of inter-worker relationships has not been examined closely in the published research. The consistency with which this issue was raised across all units in this study indicates that the issue of inter-work group relationships warrants research to examine the specific issues identified. Potential foci could be the effects of hierarchical relationships across occupations (i.e., nursing, care aide, physiotherapy) and their effect on safe work practices, levels of peer pressure between experienced and non-experienced groups (existing versus new employees) of workers and its effect on safe work practice, and the prevalence and effectiveness of working in teams on quality of care and risk factors for injury to the resident and worker.

Adaptive clothing is gaining increased use in residential care facilities. Adaptive clothing refers to clothing that is modified to increase the ease with which they can be applied to dress the resident. One example is split back dresses and shirts that are open at the back, thus allowing the resident to be dressed while sitting in their wheelchair without requiring the resident to lean forward in their chair. This results in less handling of the resident, which, in turn, reduces the level of risk associated with dressing residents. Based on the results of the focus groups, the integration of this service across all residential care settings is not yet consistent. The difficulty may lie in the perception that this is a service that is of benefit to the worker, but may compromise the dignity of the resident. This perception may be addressed by carefully planned communication of the benefits of adaptive clothing to demonstrate that there are benefits to the workers and residents. A benefit of adaptive clothing is reported to be decreased handling of the resident required during dressing and undressing tasks, which may result in a lower risk of agitation and associated less frequent aggressive or resistive behaviours of the resident. This can translate into a more pleasant day-to-day experience for the resident. Based on the results that "Dressing in Bed" received the highest ranked position for physical stress on the low back, as well as the highest average level of perceived exertion at the low back, further intervention research on the effectiveness of adaptive clothing is indicated.

Aggressive and resistive behaviour, while not solely an ergonomic issue, is often brought into the realm of injury prevention due to the frequent occurrence of work-related musculoskeletal injury of the worker as a result of these resident behaviours. These complex and multifaceted issues have been identified in the literature. However, there have been few published studies that have examined the effectiveness of interventions designed to address resident factors with the intent of reducing risk of low back injury to residential care workers.

Comparison to Previous Study

Garg *et al.* (1992) performed their study in a residential care home in the United States. The methods used in their study are similar to the ones used in the current study. Table 17 below is a comparison of tasks from the Garg study and the current study and their respective ranking results.

Table 17. Comparison of ranking results from Garg et al. (1992) and current study

Task List (Garg *et al.* 1992)	Ranked Position	Task list (current study)	Ranked Position
toilet to wheelchair	1	Dressing in bed	1
wheelchair to toilet	2	Bowel care	2
wheelchair to bed	3	Am/pm care	3
bed to wheelchair	4	Stretcher bath	4
bathtub to chair	5	Turning in bed	5
chairlift to chair	6	Boosting in bed	6
weighing patient	7	Use of lifter	7
lifting patient up in bed	8	Showering	8
repositioning patient in bed	9	Lying to sitting	9
repositioning patient in chair	10	Manual lift from floor	10
changing absorbent pad	11	Bathing in tub	11
making bed up with patient in it	12	Positioning in bed	12
undressing patient	13	Use of stander	13
tying supports	14	Toileting	14
feeding bedridden patient	15	Reposition in wheelchair	15
making bed with patient out of it	16	Bed bath	16
		1-P transfer	17
		2-P transfer	18
		Mechanical lift from floor	19
		Sitting to standing	20
		Washing in bathroom	21
		Assisted walking	22
		Feeding	23

In comparing the ranked task lists between the current study and the study performed by Garg *et al.* (1992), it is interesting to note that the first six tasks listed from the Garg study involved resident transferring tasks, whereas results from the current study identified in-bed tasks as the most stressful for the RCAs' lower backs. When comparing the mean rating scores, the six tasks given the highest rating scores in the Garg study involve transfers to or from seated positions, all of which are likely performed using a 1-person or 2-person transfer method. In the present study, these same transfer methods were located near the bottom of the list in order of rates of perceived exertion.

This shift may be a reflection of the wide-spread use of mechanical patient lifting devices within the majority of residential care facilities over the past decade. In the six study units, there was at least one mechanical patient lift device and one mechanical sit-stand device for every 20-30 residents. In some units, installations of overhead-mounted patient lifting systems improved that ratio to one dedicated lift per one to six residents. Recent studies describe the use of mechanical patient-handling equipment interventions aimed at reducing risk of injury to RCAs (Yassi *et al.* 1995, Mughal 2002, Ronald *et al.* 2002, Evanoff *et al.* 2003).

Comparison of results between the two studies was difficult due to the different task definitions and different task lists used in the two studies. Garg *et al.* (1992) defined many of the transferring tasks by the origin and destination, whereas in the current study transferring tasks were defined by the methods used to accomplish the move. This is because, in practice, a transfer from bed to wheelchair can now be performed by the RCA in four different ways: by performing a 1-person transfer, a 2-person transfer, using a mechanical sit-stand device, or by using a mechanical patient lifter.

In residential care settings, the resources that are called upon to assess resident mobility and transferring issues are primarily the physiotherapists and occupational therapists assigned to the care unit. In discussions with these individuals, and observation of practical hands-on training sessions, it was observed that vertical lifting efforts, a risk factor for injury identified in the literature (Kjellberg *et al.* 2000), can be observed in certain methods where they are not required. For example, during a boosting task, where the resident is moved up in their bed, teaching sessions encourage the use of the legs to create the movement. During on-unit observations, however, vertical lifting efforts were observed during the boosting tasks with little involvement of the legs. This minor change in technique can result in a substantial increase in loading of the low back since lifting efforts are more likely to increase compressive loading than pushing or pulling efforts.

Challenges

Injury data analysis proved to be difficult at times due to the construction of the database from which the data was extracted. The field for "body part injured" was an unstructured text field, allowing multiple body parts to be entered into one field. This issue was further exacerbated by having multiple individuals responsible for data entry into the database. This resulted in multiple terms being used for the same item (i.e., "back, lower" vs. "lower back" or "NA", "Aide", and "RCA"). A manual review of all the injury data was required for the majority of the injury data analysis to ensure the appropriate body part was identified (i.e., "back, lower leg" would not qualify as a low back injury, although it may have been included if macros were used).

Conclusions

Subjective measures reveal that in-bed positioning and care tasks are perceived by residential care workers to have the greatest level of stress and exertion at the low back. Using the rating scale, 17 of the 23 tasks were rated at or above "Somewhat Hard" and the top five tasks were rate at or above "Hard". These included "Dressing in bed", "Stretcher bath", "Am/pm care", "Turning in bed", and "Bowel care". Dressing in bed received the highest ranked position as well as the highest rating of all tasks examined in this study.

When compared to previously published studies (Garg *et al.* 1992, Owen *et al.* 1992), there has been a shift in the perceptions of risk factors of low back injury for residential care workers. This change involves lifting and transferring tasks having lower perceived physical stress and effort than in-bed positioning tasks. This presents challenges to workplace interventions aimed at reducing risks of low back injury to residential care workers, as bathing, dressing and other personal care tasks are performed slightly differently for each resident depending on their cognitive, physical and functional abilities.

Analyses of injury data indicate a 5.6% annual injury rate for first time low back injuries in residential care workers across a 578 worker population. More detailed analyses reveal full time workers experience their first low back injury at a higher age than part time or casual workers. They also are significantly older at the time of their first low back injury.

When asked for the contributing factors that increased risk in the work environment, workers reported rushing, pressure by the families, difficulties with working with co-workers and the infrequent use of adaptive clothing as factors.

Areas of future research

Based on the findings and issues identified in this study, there are a number of additional areas of research that are worth investigating. An examination of bed surfaces and positioning aides would be worthwhile to determine their effect on perceived stresses and effort during in-bed positioning tasks. The high ranking and rating of "Dressing in Bed" warrants specific investigation, specifically with the utility and effectiveness of adaptive clothing.

Aggressive and resistive behaviour may be addressed in an examination of a comprehensive assessment and management program for resident's cognitive, physical and functional abilities as it relates to effort and risk during hands-on resident care tasks.

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STUDY II: BIOMECHANICAL ANALYSIS OF WORK TASKS

Abstract

Patient handling tasks represent the single most common activity reported to have occurred at time of low back injury to residential care workers. These tasks are difficult to analyse due to the complexities involved in the handling of people rather than industrial materials.

This study examined a comprehensive list of resident care tasks performed by residential care workers in six care units. Two cameras were used to capture sagittal and coronal views of each demonstrated task during organised focus group sessions. Video frames were identified for biomechanical analysis based on posture and subjective reports of the most stressful part of the task. A commercially-available 3D biomechanical analysis software program was used to analyse the L4/L5 joint forces, including joint compressive force, A-P and lateral shear forces and joint moment.

Results indicate that workers performing patient handling tasks in residential care experience compressive loads of 467N to 3811N and A-P shear loads of 66N to 471N on a repeated basis over the course of a typical work day. Of the tasks analysed, "manual lift from floor" exceeds the NIOSH-recommended compressive load limit of 3400N. The task with the highest A-P shear force is "lying to sitting". Although "manual lift from floor" was performed infrequently, compression forces for four other tasks are within 204N of the NIOSH limit. These four tasks have a mean compression of 3207N and together are performed approximately 30 times per shift. These results suggest that the high rate of injury observed in residential care workers may be related to the

peak compressive loads of the resident care tasks and the frequencies with which these tasks are performed.

Introduction

Biomechanical analysis has been used as a means by which risk of musculoskeletal injury, particularly low back injury can be assessed for a worker population. Methods used to perform biomechanical assessments of work tasks range from the simple (pen and paper, with a measuring tape and scale) to the elaborate (2- to 6-camera lab systems, with force plates embedded in the floor, and joint markers on the subject (i.e., Opto-trak, Kintrac, Vicon)).

The NIOSH equation, first published in 1981 and revised in 1991, is likely the most commonly used paper-based model for assessing risk of injury to a worker based on task design. Waters *et al.* (1993) discussed the reasons for choosing the various limits for the revised 1991 equation. The authors identified that the three different criteria - biomechanical, physiological, and psychophysical limits - often conflict with each other, a finding that is supported elsewhere (Snook & Ciriello 1991, Mital *et al.* 1993, Dempsey 1998). Waters *et al.* (1993, 1994) list the numerous limitations in applying the equation, two of which include: It is not appropriate to apply the equation in restricted work environments or with loads whose center of mass may change during the task. Mobilizing a patient requires that the patient's centre of mass moves and changes relative to the position of anatomical landmarks throughout the transfer task. Laflin and Aji (1995) used the NIOSH equation to assess the risk of low back injury in a manual patient transfer task. The shortcoming in their approach was that the NIOSH equation explicitly excludes the handling of people from the list of tasks appropriate for assessment. In this analysis, however, static analyses are used which may address the intent of the limitation, which was the complication presented by center of mass changing during the course of the task. However, there are other limitations that affect the ability to use the NIOSH equation accurately.

A second limitation of the NIOSH equation is that asymmetric hand forces cannot be modeled, nor can hand forces be modeled to have different force vectors. Many tasks within this analysis involved either a one-handed effort (e.g., "positioning in bed", "2-person transfer", "bathing in tub", "feeding") or involved hand forces with different vectors (e.g., "lying to sitting", "use of lifter"). This shortcoming would exclude a significant portion of the tasks, specifically 12 of the 23 tasks could not be analysed using the NIOSH equation due to hand force limitations.

The NIOSH equation also assumes that other tasks performed within the workday do not account for more than 10% of all the workers' tasks. Providing nursing care to patients and residents involves several tasks that require substantial efforts (Owen *et al.*, 1992). The combined frequencies for the assessed tasks in Garg *et al.* (1992) was 25.4 per four hour shift, and the category of "other" tasks accounted for a mean frequency of 23.3 per four hour shift, resulting in "other" tasks accounting for 47.8% of the total job. Since the use of the NIOSH equation assumes that tasks that cannot be analysed using the equation should not amount to more than 10% of the total time in the job, data from Owen *et al.* (1992) would suggest that the use of the NIOSH equation to residential care work would be inappropriate.

Waters *et al.* (1993) also mention that there is a paucity of epidemiological evidence to support the causal relationship between the criteria in the equation and the relative risk of injury. Other studies also report a lack of epidemiological evidence to support the NIOSH equation (Dempsey 1998, Kumar and Mital 1992). Waters *et al.* (1993) and Hignett and McAtamney (2000) specifically identify the inability of the NIOSH model to be applied to the handling of people as the justification for the need to develop an assessment method specifically designed for the healthcare work environment.

In 1999, Marras *et al.* assessed patient handling tasks using the Lumbar Motion Monitor system. This more elaborate data acquisition method provided robust data, however the methods used relied on an exoskeleton to be worn on the trunk.

Previous reports have established the high costs and days lost due to musculoskeletal injury in the healthcare industry, as well as the high rates of injury to residential care workers when compared to the rest of healthcare (WCB of BC 2000, 2002). Subjective evaluations of patient handling tasks indicate that there are tasks rated as having high levels of exertion that are also highly ranked by workers as having high levels of physical stress on the low back (see Table 12).

It was important to this researcher that the methods used in this study would contribute to the development of a substantive tool that could be used by an Ergonomist in the field to assess risk of low back injury. It needed to be non-invasive, portable, not complex to perform, not interfere with the tasks or operations of the workplace, not overly dependent on equipment, provide the necessary data for biomechanical analysis of low back joint compression forces, and have a biomechanical basis for the assessment and evaluation of low back injury risk.

This study examined a comprehensive list of tasks regularly performed by residential care workers using a commercially available 3D biomechanical analysis software package. It evaluated joint loading in biomechanical terms, reporting low back compression and joint shear forces, as well as joint moments at the L4/L5 spinal level. Given the high rates of LBI in this industry, we hypothesized that the joint compression forces at L4/L5 will exceed the NIOSH guidelines.

Methods

Subjects

A total of six focus groups were organized at six different residential care units across a large healthcare employer in BC. Resident Care Attendants (RCAs) from each unit were invited to voluntarily participate in a focus group for their unit; eight participants were included for each focus group. All subjects were provided with written project information and provided voluntary informed consent prior to participating in the study. A total of 45 subjects participated in a sub-study involving simulation and biomechanical analysis of routine tasks.

The protocol used in this study was reviewed by and received approval from Simon Fraser University's Research Ethics Board.

Data collection

Formally structured focus groups were conducted in each of the six care units. The focus groups included workers from each of the three employment status group: full-time, part-time and casual. No effort was made to selectively invite workers with or without a history of injury to participate in the focus groups. For each focus group, a space was identified where a bed, wheelchair and appropriate patient handling devices were made available to be used by the volunteer workers.

One purpose of the focus group was to determine the critical tasks that are performed by residential care workers. This was developed by having each group list the tasks that they felt contributed most to injuries in their work environment. Once the list was developed, the workers were then asked to rank and rate the tasks according to levels of perceived physical stress and exertion at the low back (see Table 12 for a summary of these data). Once the paper exercises were completed, each worker's height and mass were measured and entered into a spreadsheet (Microsoft Excel 2002®). The workers were asked to demonstrate the tasks as they would perform them on the care unit. A volunteer from the group was asked to perform the role of a "resident". One or two volunteer workers (two workers if it was a two-person task) were asked to demonstrate the typical methods used to perform a specific task (e.g., 1-person transfer). The rest of the subjects in the group would evaluate and comment on the methods used by the workers, and modify it if necessary. The next step was taken only after everyone was in agreement as to the most appropriate method to use for data collection purposes. The final step prior to data collection was to ask the group to identify the moment (posture and direction of hand forces) in each task that they felt presented the greatest risk of injury or applied the greatest stress to their low back.

Each worker performed at least one trial of the task for data collection purposes. Trials were repeated if there was an error in task performance or data collection. (Based on feedback from the second focus group session, workers were cycled through trials and allowed to perform a maximum of two trials in succession to reduce risk of muscular fatigue associated with task performance during data collection). Direct force measures were taken when it was possible to put the force dynamometer (Chatillon Strength Dynamometer, model CSD200, Ametek, Largo, FL, USA, 2001) in-line during task performance without adversely affecting biomechanics during task performance. When this was not possible, force replication was used to determine force exerted during task performance. Methods used were similar to those used by Norman *et al.* (1999) in their study of injury risk in the automotive assembly industry. Force replication involved asking the worker to replicate the force used during the task immediately after task performance, with the dynamometer positioned in a similar direction and location during the peak force exertion. The position and moment in the task at which force measures were replicated was predetermined prior to the start of the trials for each task (based on the consensus of the focus group as to the posture and forces that presented the greatest risk of injury or applied the greatest stress to the back). Where both hands were exerting forces in a symmetrical and coordinated manner, one force measure was taken. When both hands were moving in different directions and at different times, force measures were obtained for each hand separately.

During task performance, two simultaneous video images were captured using two digital cameras (Canon digital cameras, models A70 & A80; JVC digital video camera, model GR-D91U). One captured a sagittal view; the other captured a posterior view in the coronal plane. A posterior view was used as the anterior view was obstructed the bed and the volunteer "resident model".

The above steps were repeated for each task on the focus group's task list. Where it was deemed by the researcher that the methods used by one focus group were similar to those used by a previous focus group, task modeling was not performed.

Analysis

Once data were collected from all focus groups, the data were processed to first determine an appropriate representative trial for each task, and then to select the most appropriate frame from each trial that was selected. Once that was completed, the postures were modeled in biomechanical software.

In order to select the representative trial for a task, variables for each task were compiled into a spreadsheet (SPSS v12.0.0, SPSS Inc., Chicago, Illinois, USA, 2003) including subject height, subject mass, and hand force exerted. Normalized scores were calculated for each task's variables, providing each trial with a set of three scores, which were then used to determine the root-mean-square error (rms error) value for each trial. The trial with the lowest rms error was selected to provide actual data to represent that task.

Once the representative trial was identified, both sagittal and posterior coronal video scenes were brought into video editing software (Pinnacle Studio 8, Pinnacle Systems, Inc., USA, 2002). Using the moment identified by the focus groups that represented the greatest perceived risk of low back injury or greatest stress on the low back, the frame that represented that moment was captured into a JPEG file. For each task, there were two images: one of a sagittal view and one of a posterior coronal view. These two images were used to model the task in the biomechanical analysis software.

A number of options for biomechanical analysis methods were considered for this study. A novel model could have been developed, but this would have required postural markers in the video data, much like the methods used for in-lab biomechanical studies. This approach, although attractive, was considered too intrusive and time consuming to be suitable for use in the development of an ergonomic tool to be used in the field, as described in the Introduction. A Canadian biomechanical analysis software program (4D WATBAK, University of Waterloo, Ontario, Canada) was available on the market; but at the time of this study it only allowed for two-dimensional analysis of postures in the sagittal plane, which limited the ability to assess the majority of work tasks observed in the residential care environment. The decision to use 3DSSPP v4.3.6, developed by the University of Michigan (Ann Arbor, MI, USA, 2003,) was based on the facts that it is a well developed tool allowing for analysis of postures in three dimensions, it provides compression and shear forces as well as joint moments, and is fairly easy to use. It uses biomechanical models developed by Chaffin and Anderson (1984) and uses a 10-muscle model of the low back. Inputs into 3DSSP include subject height, subject mass, hand forces in each hand (including direction), as well as body posture during force exertion.

Using the two images captured for each representative trial, the posture of the mannequin provided in 3DSSP was adjusted to represent as closely as possible the posture of the volunteer RCA subject depicted in the representative images. The direction of hand force was approximated based on the position and direction of applied force and movement as viewed in the videos. The subject's height, mass and hand forces exerted were entered into the program. When the task was two-handed and the force was measured by using both hands on the transducer during exertion, the forces were divided equally between both hands. When tasks required different movements of each hand, separate force data were collected and entered (magnitude and direction) for each hand.

The output of each biomechanical analysis consisted of peak compression force and shear forces in the anterior-posterior (A-P) and lateral directions (measured in Newtons) at the spinal level of L4/L5, joint moment about L4/L5 (measured in Newton metres (Nm)), trunk forward flexion angle, axial rotation angle and lateral flexion angle (measured in degrees).

Results

Figure 12 through 14 provide examples of the information involved in the biomechanical analysis process. Figure 12 shows the two types of images (sagittal and coronal) that represent the types of images captured from the data collection sessions. Figure 13 is a screenshot of the working window of the biomechanical analysis software, showing the analysis of the task as shown in Figure 12. Figure 14 shows a typical report that is produced by the software that summarizes some of the data used in this study.

Figure 12. Sagittal and coronal images captured from video

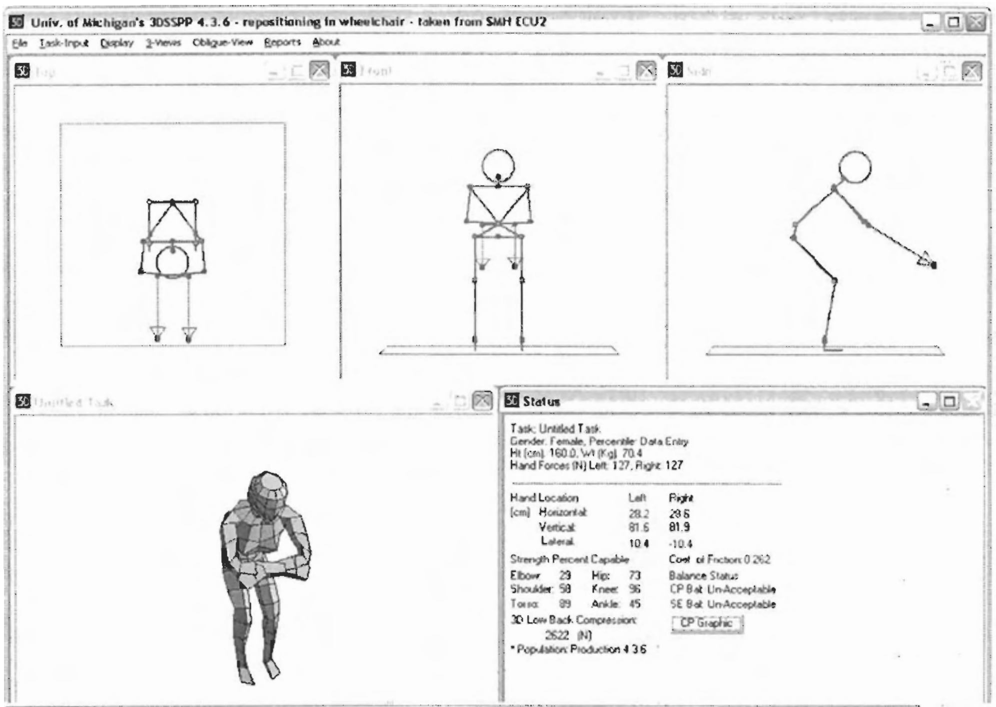
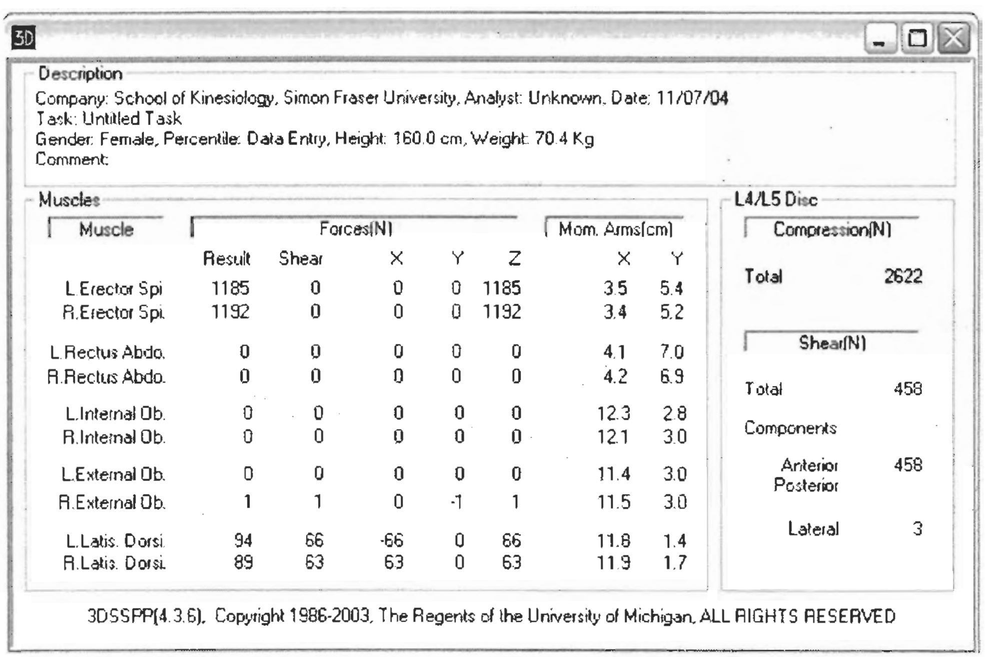


Figure 13. Screenshot of biomechanical analysis software



Description
Company: School of Kinesiology, Simon Fraser University, Analyst: Unknown, Date: 11/07/04
Task: Untitled Task
Gender: Female, Percentile: Data Entry, Height: 160.0 cm, Weight: 70.4 Kg
Comment:

Muscles

Muscle	Forces(N) Result	Shear	X	Y	Z	Mom. Arms(cm) X	Y
L.Erector Spi	1185	0	0	0	1185	3.5	5.4
R.Erector Spi.	1192	0	0	0	1192	3.4	5.2
L.Rectus Abdo.	0	0	0	0	0	4.1	7.0
R.Rectus Abdo.	0	0	0	0	0	4.2	6.9
L.Internal Ob.	0	0	0	0	0	12.3	2.8
R.Internal Ob.	0	0	0	0	0	12.1	3.0
L.External Ob.	0	0	0	0	0	11.4	3.0
R.External Ob.	1	1	0	-1	1	11.5	3.0
L.Latis. Dorsi.	94	66	-66	0	66	11.8	1.4
R.Latis. Dorsi.	89	63	63	0	63	11.9	1.7

L4/L5 Disc

Compression(N) Total	2622
Shear(N) Total	458
Components	
Anterior	458
Posterior	
Lateral	3

3DSSPP(4.3.6), Copyright 1986-2003, The Regents of the University of Michigan, ALL RIGHTS RESERVED

Figure 14. Data table from biomechanical analysis software

Table 18 lists the 23 tasks analysed, the hand forces used and predicted forces and moments at L4/L5 calculated for each task, along with three postural angles to provide context for the task. Forward flexion of the trunk is measured as 0° representing an upright neutral posture; positive values are in the forward (flexion) direction. Axial rotation is measured from neutral standing, positive values represent rotation in the counter-clockwise direction. Lateral flexion is measured from upright neutral posture, positive toward the subject's right side.

Results show that the maximum compressive force experienced among these tasks was 3811N for "manual lift from floor". The top five tasks for peak compressive forces are "manual lift from floor", "sitting to standing", "1-person transfer", "toileting", and "boosting in bed". The task with the greatest level of A-P shear force is "lying to sitting" at 471N. The top six tasks for peak A-P shear are "lying to sitting", "repositioning in wheelchair", "turning in bed", "sitting to standing", "1-person pivot", "toileting" (the last three tasks had equivalent levels of A-P shear). Lateral shear forces were generally low with the exception of "boosting in bed" and "lying to sitting" with 328N and 154N, respectively.

Table 18. Hand force values and predicted forces, moments at L4/L5, and trunk posture

Task	Hand Force (N)		Compression (N)	A–P Shear (N)	Lateral Shear (N)	Joint Moment (Nm)	Trunk forward flexion (°)	Trunk axial rotation (°)	Trunk lateral flexion (°)
	Left	Right							
Dressing in bed	148	0	2281	219	14	-97.3	31	6	1
Bowel care	79	158	1320	136	1	-45.8	1	0	0
Am/pm care	148	0	2281	219	14	-97.3	31	6	1
Stretcher bath	148	0	2281	219	14	-97.3	31	6	1
Turning in bed	119	119	1178	398	2	-51.5	28	0	0
Boosting in bed	147	147	2812	367	328	-68.9	23	10	-9
Use of lifter	50	50	695	66	11	-17.1	11	-5	1
Showering	42	42	2709	159	3	-119.3	39	0	0
Lying to sitting	126	90	2779	471	154	-105.8	81	0	0
Manual lift from floor	111	111	3811	230	5	-154.6	39	0	0
Bathing in tub	148	0	2281	219	14	-97.3	31	6	1
Positioning in bed	0	192	3239	309	22	-154.4	47	21	0
Use of stander	53	53	695	66	11	-17.1	11	-5	1
Toileting	94	94	3196	347	1	-152.3	36	0	0
Reposition in wheelchair	127	127	2622	458	3	-128.0	47	0	0
Bed bath	148	0	2281	219	14	-97.3	31	6	1
1-P transfer	94	94	3196	347	1	-152.3	36	0	0
2-P transfer	0	182	2568	205	-32	-98.6	37	20	-20
Mechanical lift from floor	79	79	2793	77	7	-120.8	28	0	0
Sitting to standing	94	94	3196	347	1	-152.3	36	0	0
Washing in bathroom	0	98	2287	87	92	-85.8	56	-9	30
Assisted walking	0	10	495	154	6	2.0	1	-20	0
Feeding	5	0	418	113	3	-5.3	1	-21	0

Discussion

"Manual lift from floor" was the only one of the 23 tasks analysed that exceeded the NIOSH guidelines (Waters *et al.* 1993). However, when compared to the lifting limit of 2698N, published by Mital *et al.* (1993), nine of the tasks exceeded the limit. These nine tasks are "manual lift from floor", "positioning in bed", "toileting", "1-p transfer", "sitting to standing", "boosting in bed", "mechanical lift from floor", "lying to sitting" and "showering". These nine tasks represent a mean compressive load of 3081N per task and an average daily exposure of 50 times per shift. These findings represent a considerable lifting burden for a predominantly female worker population.

Comparison to other studies

There are several studies that have examined patient handling tasks. Table 19 lists a summary of the means and standard deviations of compression values obtained from these studies found in the literature. Only those tasks that were similar in method of performance are listed in the table.

There are some challenges in comparing biomechanical data across studies. Not all studies have task descriptions that allow the reader to determine if the terms are used in the same manner across studies. Some of the studies report compressive forces in the components of a transfer task, using "wheelchair to bed" or "bed to wheelchair" as opposed to "use of lifter", "2-person assist transfer". The manner in which tasks are defined have not yet been standardized. The latter form of reporting and analysing tasks allow for easier comparisons among studies.

In comparison to previous studies, the predicted compressive force values obtained in this study are generally within the range of values reported. The mean compression force calculated in this study is low for “use of lifter”, “use of stander”, “bowel care”, “turning in bed”, “turn toward”, “turn away”, and “horizontal repositioning”. However in most of these tasks, there is only one comparative value available from previous studies. The few substantial differences that exist could be explained by differences in the portion of the task that was analyzed (e.g., start or the end of the transfer), or by the methods that were used to perform the task (e.g., boosting using one worker versus two workers). It is also possible that the quality and effectiveness of assistive devices differ, and have improved in recent years.

Table 19. Comparison of means and standard deviations (inside brackets) of compression values reported in this study and previous studies

Task	Mughal (2004)	Schibye *et al.* (2003)	Skotte *et al.* (2002)	Daynard *et al.* (2001)	Zhuang *et al.* (1999)	Marras *et al.* (1999)	Varcin-Coad & Barrett (1998)	Garg *et al.* (1992)
Bowel care (turn away)	1320	1909 (562)			2786 (708)			
Turning in bed	1178			1759.2 (308.4)				
Boosting in bed	2812	1991 (369)	3094 (591)	3076.4 (199.2)		3902.5 (1273.6)		
Use of lifter	695			1367.3 (248.1)				
Lying to sitting	2779	1909 (355)	3091 (412)		3676 (572)			
Use of stander	695			2555.6 (191.2)				
Toileting	2294							
Reposition in wheelchair	2622	3326 (722)	4433 (666)	2743.4 (505.9)			4589*	
1-P transfer	3196	2708 (520)				6336.6 (2044)		3991 (n/a)
2-P transfer	2568			2010 (270.4)				
Sitting to standing	3196	2708 (520)	4132 (631)					
turn toward	925	1603 (326)	1618 (322)		3081 (531)			
horizontal repositioning	1178	2442 (717)	3179 (631)					

**approximated based on data available*

Given that the methods used to collect hand force values and subsequently predict compressive forces at L4/L5 were developed for in-field data collection, the present study is encouraging for ergonomists interested in obtaining objective data in more realistic settings than laboratory simulations. The present method, while requiring one or two digital cameras and a force dynamometer, is relatively easy to implement when compared to a multi-camera motion analysis system. No preparation of the subject is required, other than to ensure there is adequate ambient lighting to ensure clear visual pictures of the worker's posture as it is performed. This method is extremely valuable when attempting to accurately assess tasks that are difficult to reproduce in the laboratory environment, or when access to a laboratory environment is difficult.

Comparison to biomechanical lifting limits

The methods behind the development of the 1991 revised NIOSH equation are discussed by Waters *et al.* (1993). The authors discuss the justification for the 3400N action limit for compressive loads on the low back. Based on cadaver data, it was determined that 3400N protected the majority of the work force, specifically 99% of male workers and 75% of the female working population. The alternate interpretation is that, at or below 3400N of compressive loading, an average of 25% of the cadaver lumbar spinal specimens had experienced damage or failure. As that the majority of healthcare workers are female, an action limit that protects 75% of female workers may provide limited protective value to the healthcare industry.

Mital *et al.* (1993) suggests a lower lifting limit for female workers, based on ultimate strength studies performed on cadaver specimens. They suggest the safe compressive loading limit for females is 2698N, which assumes 70% of the female working population would be protected.

Genaidy *et al.* (1993) examined the published cadaver data to determine the relationships between ultimate compressive strength and individual characteristics such as age, gender, spinal level, and body weight of the subject from which the sample was taken. The authors utilized a number of data sources on failure strength of vertebral spinal units (two adjacent vertebrae with the intervertebral disc, along with the ligamentous structures and posterior spinal elements), vertebrae and intervertebral discs. They analyzed the data to examine the effects of age, gender, spinal level and body weight. They were able to develop a regression equation that incorporates factors for each of the above variables. Using the average age at time of LBI from Study I, the ultimate compressive strength for this female worker population would be 6201N. Assuming a 70% protective rate, as used by Mital *et al.* (1993), the safe loading limit using the data from Genaidy *et al.* (1993) would be 1860N. This is considerably lower than the limits published by either NIOSH (Waters *et al.* 1993) or Mital *et al.* (1993); however data from Genaidy *et al.* (1993) is based purely on cadaver studies, whereas the NIOSH limit is largely based on field studies where injury data were compared to compression forces of tasks performed (Waters *et al.* 1993).

The compression values obtained for each task, along with the NIOSH Action Limit (Waters *et al.* 1993) and the limit for female workers determined by Mital *et al.* (1993), are presented in Figure 15.

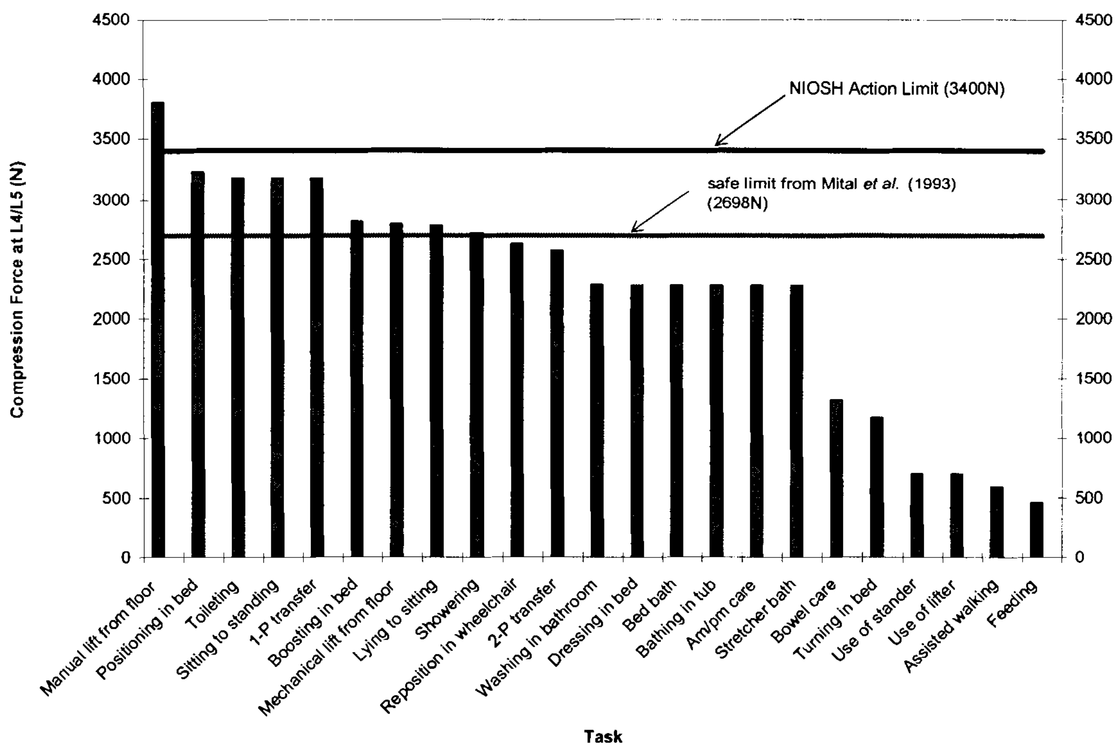


Figure 15. Comparison of predicted compression values for each task to published compressive load limits

With respect to the data from this study, only one task exceeds the NIOSH Action Limit ("manual lifting from the floor"). This task, however, occurs on an infrequent basis, an average of only 0.3 times per shift as shown in Table 12. There are four additional tasks that are within 204N of the limit ("positioning in bed", "toileting", "1-p transfer", and "sitting to standing"). Combined with the first task, they provide an average of 3328N of joint compression at L4/L5 occurring a total average frequency of almost 30 times per shift.

If the limit of 2698N, published by Mital *et al.* (1993), is used as a safe lifting limit, there are nine tasks in total that would exceed the safe lifting limit. These nine tasks are "manual lift from floor", "positioning in bed", "toileting", "1-p transfer", "sitting to standing", "boosting in bed", "mechanical lift from floor", "lying to sitting", and "showering". Together, the top eight tasks would represent an average compression force of 3081N at L4/L5 per task occurring at an average total frequency of almost 50 times per shift.

Five of the previous studies report compression values above the NIOSH Action Limit (Skotte *et al.* 2002, Zhuang *et al.* 1999, Marras *et al.* 1999, Varcin-Coad & Barrett 1998, Garg *et al.* 1992). The remaining two studies report compression values very close to the Action Limit (>3000N) in one or more tasks. Compression values close to and above the Action Limit are also found in this study. Given that all hands-on care workers in residential care, such as RCAs, perform these tasks on a regular basis, repeatedly during each shift on every shift, one would expect a high injury rate based on both the NIOSH limit and the limit determined by Mital *et al.* (1993).

Anterior-posterior shear forces were noted to be high for some tasks, namely "boosting" (367N), "turning in bed" (398N), "positioning in bed" (309N), "lying to sitting" (471N), and "repositioning in a wheelchair" (458N). Other tasks had shear forces that were similar, including "1-person transfer" and "sitting to standing" (347N for each). Shear forces have been correlated in the literature with injury risk (McGill 1997). However, it is difficult to assess the level of risk associated with the A-P shear forces due to the absence of accepted exposure limits for these forces. Yingling and McGill (1999) proposes a limit of 500N, but this is based on extrapolations from a porcine model and observed injury data, not destructive testing of human vertebral tissues. Therefore, in absence of better data of shear strength, it is difficult to draw conclusions regarding risk of injury in residential care workers due to shear forces.

Issues encountered with modeling tasks

When modeling the tasks captured during the focus groups, there were a number of challenges with accurately representing the tasks within the biomechanical software.

While adjustment of the mannequin in the software is fairly straightforward, there were limitations in what positions could be modeled at specific joints. Hip abduction is not permitted, which is what is encountered during many boosting tasks where the movement is lateral to the subject's initial feet location. In addition, internal or external hip rotation is not available. This movement would be beneficial when analyzing squatting positions, allowing for additional flexion of the trunk. The software does not permit any other body segment to be supporting the weight on the floor other than the feet. This eliminates the ability to analyse kneeling postures or postures where a subject has one knee on the bed surface while performing a task.

There were also some issues that were not barriers to analysis, but, had they been addressed earlier, analysis would have been much simpler. One such issue was the distance of the cameras to the subject. This measure was not controlled for because the room sizes were different from unit to unit and facility to facility. The biomechanical analysis software allows for the input of the focal length, distance to the subject and angle of view to modify the display of the mannequin on screen, allowing it to more closely match the still images used in the replication of the posture.

Conclusions

Joint compression values calculated were found to be high in the majority of tasks, and were close to or above the NIOSH Action Limit in four of the 23 tasks analysed. If the lifting limit proposed by Mital *et al.* (1993) is used, 11 of the 23 tasks are categorised as unsafe. Given the repetitive nature of these tasks, and a predominantly female population, it is concluded that the residential care workers are exposed to high risk of low back injury.

The compression values calculated for most tasks in this study are in agreement with values found in previously published findings for compressive loading at L4/L5 for patient handling tasks. Shear forces in the anterior-posterior direction, as well as in the lateral direction, were noted to be high for specific tasks. However, the contribution of these forces to probability of low back injury is difficult to assess due to the absence of accepted threshold or ultimate strength values for the low back structures in these directions.

Areas of future research

The methods used in this study to analyse posture and forces during patient handling tasks were not novel and have been used in other published research (Kumar 1990, Norman *et al.* 1998, Daynard *et al.* 2001). However, there remains an absence of validation studies to establish the accuracy of these measurement techniques. Studies that would examine the accuracy of the posture analysis and force-replication methods are warranted.

Based on the identification of a number of tasks with high A-P shear forces in this study, examination of ultimate strength of vertebral spinal unit in the A-P shear direction would allow for the assessment of risk associated with these forces.

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STUDY III: COMPARISON OF SUBJECTIVE AND OBJECTIVE MEASURES OF WORKPLACE RISK FACTORS FOR LOW BACK INJURY

Abstract

The healthcare environment has been assessed by several investigators for risk of low back injury. Typically, analysis will involve either reports of perceived risk or objective measures of risk of injury. However, analyses are limited in the range of tasks evaluated, assumptions regarding forces involved in patient-handling tasks, and relationship between objective measures and perceived risk.

This study examined the relationships of subjective measures of perceived stress and exertion at the low back to objective measures of hand force, trunk posture, and calculated values of joint moment and forces at the low back. The tasks analysed were derived from a comprehensive study of work performed by residential care workers, using volunteer workers at six different residential care units.

Correlation analyses revealed limited relationships between the subjective and objective measures of risk. There were strong correlations between subjective measures of ranking (stress) and rating (exertion), and among objective measures of hand force, L4/L5 joint compressive force, A-P shear force, joint moment and trunk posture ($p<0.05$). Hand force was also found to be positively correlated with subjective rating of exertion ($r=0.45$, $p=0.03$). However, there were no significant correlations between subjective measures stress and exertion and the objective measures of joint loading at the low back (compressive and shear forces, and joint moment) or trunk posture.

These findings suggest that the perceptions of workers regarding risk of low back injury may be influenced by the levels of forces at the hands rather

than stress at the low back. It is likely that other factors play a role in perceived risk. Possible factors include the duration of postures held, duration of tasks, level of aggression or resistance demonstrated by residents, or the unpredictable nature of residents' behaviour.

Introduction

Assessment of risk of low back injury is a key concern for the healthcare industry. Low back injuries (LBIs) are the most common type of work-related injury suffered by workers in British Columbia (BC), accounting for 30% of all injuries reported to the Workers' Compensation Board of British Columbia (2002). In a focus report on work-related injury in healthcare, the Workers' Compensation Board of British Columbia reported that back injuries accounted for 36% of injuries in healthcare during the period of 1994 to 1998, and 38% of all injuries reported were related to patient handling for the same period (WCB, 2000). More recent statistics indicate that the prevalence of patient handling injuries remained high through 2001, with 34% of time loss injuries and 41% of all healthcare claims costs in BC associated with patient handling (WCB of BC 2002). When compared to all other industries in BC, healthcare had the highest number of overexertion claims (5,255 reported injuries), the highest number of days lost (412,000) and the greatest short-term disability claims costs ($48 million) in 2001 (WCB of BC 2002). Nurse aides, licensed practical nurses and care aides accounted for 34% of all injury reports in healthcare from 1994 to 1998, the most of all occupational groups. For this same group, back injuries accounted for 52% of all reported injuries related to patient handling (WCB of BC 2000).

Assessment of risk of LBI in healthcare has been reported on numerous occasions in the literature. Patient handling tasks in healthcare have been identified as a high-risk task group in studies where historical data was examined (Owen *et al.* 1992, Yassi *et al.* 1995, Bewick and Gardner 2000). Studies have examined the activities immediately preceding incidence of injury, through interviews post-injury (Yassi *et al.* 1995, Engkvist *et al.* 1998), and through assessments with biomechanical models (Holliday *et al.* 1994, Winkelmolen *et al.* 1994, Laflin and Aji 1995, Marras *et al.* 1999, Lynch and Freund 2000). Laflin and Aji used the NIOSH equation, in effect to justify the acquisition of mechanical patient handling devices. Marras *et al.* (1999) used an elaborate exoskeleton and collected data in a laboratory setting.

In 1992, Owen *et al.* examined rates of perceived exertion for resident care tasks and also predicted levels of compression at L4/L5. The methods used to perform biomechanical analysis were similar to those used in Study II of this paper, with the exception of the collection of hand forces. In their study, Owen *et al.* (1992) assumed that one-half the resident's mean body weight equalled the hand force input for one caregiver during the performance of a two-person task. This assumption, and the results from Study II, brings the current applicability of their findings into question.

Similarly, Winkelmolen *et al.* (1994) compared a number of common patient handling techniques and determined the compression values at the low back and levels of exertion required by nursing staff, and the relationship between these variables. While they found significant correlations between rates of perceived exertion and compressive forces at the spinal level of L5/S1, they did not report the assumptions or data used to represent the force input into their biomechanical model. It is therefore difficult to determine the accuracy of their forces, and hence, the validity of their correlation findings.

All of the previous studies performed on patient handling tasks used a subset of tasks from the overall task list for patient handling for that work environment, thus limiting the utility of the data in modeling risk of injury using occupational exposure.

One study examined a range of simple lifting tasks to determine the relationship between perceptions of exertion and compression in the lumbar spine (Waikar *et al.* 1991). They compared five lifting tasks that had non-overlapping lifting ranges and were performed only in the sagittal plane. While they did not calculate the correlation coefficients for the subjective and objective measures, they reported that tasks with high levels of compression at the L5/S1 spinal level were rated low on the subjective ratings of exertion. This discrepancy raises questions about the actual relationship between the reported rates of exertion and biomechanical measures.

The first study in this thesis had shown that, over the last 12 years, a shift has occurred in workers' perceptions of stresses and exertion at the low back during the performance of resident care tasks. The second study provides the compression values for the same resident care tasks. Using these data, the current study examined the relationship between subjective measures of perceived physical stress and exertion at the low back and the objective force measures associated with patient handling tasks performed in residential care environments. We hypothesize that there will be significant correlations between subjective measures of risk of low back injury and objective measures of joint force compression and moment at the spinal level of L4/L5. The results from this study were compared to the previously published studies that examined the relationship between objective and subjective measures of risk in residential care.

Methods

Using data collected in previous studies (Study I and Study II above), this study examined the relationships between the subjective and objective measures of risk.

Study I obtained subjective reports of stress on the low back for each resident care task by way of a ranking exercise. Focus groups were assembled in six different residential care units with eight voluntary worker participants in each group. The group was asked to develop a list of the most physically demanding tasks in their regular work routine. For the ranking exercise, each worker was provided a copy of the list and asked to identify the task that presented the most physical stress on their low back. Once they gave that task a rank of "1", they were asked to identify the next most physically stressful task for their low back and label that task with "2", and so on down the list until all tasks were given a rank score. Rating scores were obtained in the same manner using a separate worksheet, but for this exercise workers were asked to provide a rating of perceived exertion based on the scale developed by Borg (1990). These rankings and ratings were collected from each worker in each focus group and processed to provide mean and standard deviation values for each task in each exercise (ranking and rating).

Study II asked the workers in the same focus group to demonstrate the part of each task that was the most difficult. The group arrived at a consensus as to the method used for each task as well as the portion of the task that was to be modeled. Each subject's height and mass were recorded into a spreadsheet (Microsoft Excel 2002®). Each task was performed by each worker as a subject, with one worker acting as a resident appropriate to the type of task being simulated (i.e., a resident requiring a 2-person pivot transfer will be more physically dependent than a resident appropriate for a 1-person pivot transfer). Task performance was captured using two digital video devices (Canon digital cameras, models A70 & A80; JVC digital video camera, model GR-D91U), one obtaining a sagittal image and the other obtaining a coronal image. Hand force values were captured using either a direct measure or a force replication method using a force dynamometer (Chatillon Strength Dynamometer, model CSD200, Ametek, Largo, FL, USA, 2001). The subject height, mass and hand force values for each trial were processed for each task to obtain root-mean-square (rms) errors for each trial (subject profile data are listed in Table 10, hand force values are listed in Table 18); the trail with the lowest rms value was selected to be the most representative trial for that task. The video images were downloaded onto a computer using video editing software (Pinnacle Studio 8, Pinnacle Systems, Inc., USA, 2002) and the frame representing the portion of the task with the greatest level of difficulty was captured. This provided two images for each task, one from each camera. These images were then used as references by the investigator when modeling the posture of a mannequin in a packaged biomechanical analysis software program (3DSSP, University of Michigan, 2003). The hand force, subject height and mass were inputs into the model, and the hand force vector direction was established using the video data as a reference. The outputs of this biomechanical analyses were lumbar joint compression, anterior-posterior (A-P) shear, lateral shear and joint moment at the spinal level of L4/L5.

Analysis

The subjective and objective measures obtained from the previous two studies for each of the 23 tasks were entered into a statistical software program (SPSS v12.0, SPSS Inc., USA, 2003). The first correlation matrix was generated using the following subjective and objective measures from each study: subjective stress on the low back, subjective rate of perceived exertion at the low back, lumbar compression force at L4/L5, corresponding lumbar shear forces in the A-P and lateral directions, joint moment at L4/L5, hand force and forward flexion of the trunk. The software was then used to calculate a simple rank score for the all variables included in the analysis. A second correlation matrix was generated using the rank values for each variable. Pearson correlation coefficients were obtained with significance reported at 0.05 level, two-tailed.

Results

The correlation analysis of the actual values for the variables is shown in Table 20. The correlations for the variables rate, rank, hand force, compression, A-P shear, lateral shear, joint moment and forward flexion of the trunk are provided, together with significance.

Table 20. Pearson Correlation coefficients for actual values for subjective and objective measures for resident care tasks (n=23)

		Rank	Rate	Compression (N) at L4/L5	Hand Force (N)	A-P Shear (N)	Lateral Shear (N)	Joint Moment (Nm)	Forward Flexion of Trunk
Rank	Pearson Correlation	1							
	Sig. (2-tailed)	.							
Rate	Pearson Correlation	-.884(**)	1						
	Sig. (2-tailed)	.000	.						
Compression (N) at L4/L5	Pearson Correlation	-.099	.208	1					
	Sig. (2-tailed)	.653	.342	.					
Hand Force (N)	Pearson Correlation	-.389	.441(*)	.494(*)	1				
	Sig. (2-tailed)	.067	.035	.017	.				
A-P Shear (N)	Pearson Correlation	-.147	.224	.461(*)	.636(**)	1			
	Sig. (2-tailed)	.502	.305	.027	.001	.			
Lateral Shear (N)	Pearson Correlation	-.135	.180	.171	.297	.306	1		
	Sig. (2-tailed)	.539	.412	.434	.168	.155	.		
Joint Moment (Nm)	Pearson Correlation	.061	-.203	.942(**)	.499(*)	-.505(*)	.076	1	
	Sig. (2-tailed)	.782	.353	.000	.015	.014	.731	.	
Forward Flexion of Trunk	Pearson Correlation	-.183	.335	.698(**)	.268	.540(**)	.170	.675(**)	1
	Sig. (2-tailed)	.405	.119	.000	.217	.008	.438	.000	.

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Results from Table 20 show that there is a significant relationship between rate and rank scores ($r=-0.88$, $p<0.001$), and also between rate scores and hand force ($r=0.44$, $p=0.04$). It is of note that the Pearson correlation coefficient between rank scores and hand force is just beyond statistical significance ($r=-0.39$, $p=0.07$). There is no significant relationship between the remaining objective measures (L5/L5 joint compression, A-P shear, lateral shear, joint moment and trunk flexion) and either of the subjective measures.

Among the objective measures, there is a strong correlation between joint moment and compression force ($r=0.94$, $p<0.001$), between forward flexion and compression force ($r=0.70$, $p<0.001$), between forward flexion and joint moment ($r=0.68$, $p<0.001$), and between hand force and A-P shear force ($r=0.64$, $p=0.001$). There are also significant correlations between joint compression force, A-P shear and hand force, among joint moment, A-P shear and hand force and between forward flexion and A-P shear force.

For the next analysis, each variable was recoded to provide a rank value, using methods similar to those used by Owen *et al.* (1992). The data from the second correlation analysis are shown in Table 21. Recoding the variables into rank values identified a new significant relationship between rate and lateral shear ($r=0.44$, $p=0.4$). However, the significant relationship between hand force and rating scores was lost when the variables were converted to rank values.

Table 21. Pearson Correlation coefficients for ranked values for subjective and objective measures

		RANK of Rank	RANK of Rate	RANK of Compression	RANK of Hand Force	RANK of A-P Shear	RANK of Lateral Shear	RANK of Joint Moment	RANK of Forward Flexion
RANK of Rank	Pearson Correlation	1							
	Sig. (2-tailed)	.							
RANK of Rate	Pearson Correlation	.857(**)	1						
	Sig. (2-tailed)	.000	.						
RANK of Compression	Pearson Correlation	-.017	-.057	1					
	Sig. (2-tailed)	.940	.798	.					
RANK of Hand Force	Pearson Correlation	.148	.117	.479(*)	1				
	Sig. (2-tailed)	.500	.596	.021	.				
RANK of A-P Shear	Pearson Correlation	.245	.221	.476(*)	.629(**)	1			
	Sig. (2-tailed)	.261	.310	.022	.001	.			
RANK of Lateral Shear	Pearson Correlation	.304	.436(*)	.051	-.173	.051	1		
	Sig. (2-tailed)	.159	.038	.817	.431	.816	.		
RANK of Moment	Pearson Correlation	.111	.122	-.852(**)	.482(*)	.501(*)	.206	1	
	Sig. (2-tailed)	.614	.580	.000	.020	.015	.346	.	
RANK of Forward Flexion	Pearson Correlation	.066	.090	.688(**)	.174	.452(*)	.119	.715(**)	1
	Sig. (2-tailed)	.767	.684	.000	.428	.030	.587	.000	.

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Graphical representations of the strongest correlations found in Table 20 (actual values correlation analysis) are shown in Figures 16-22.

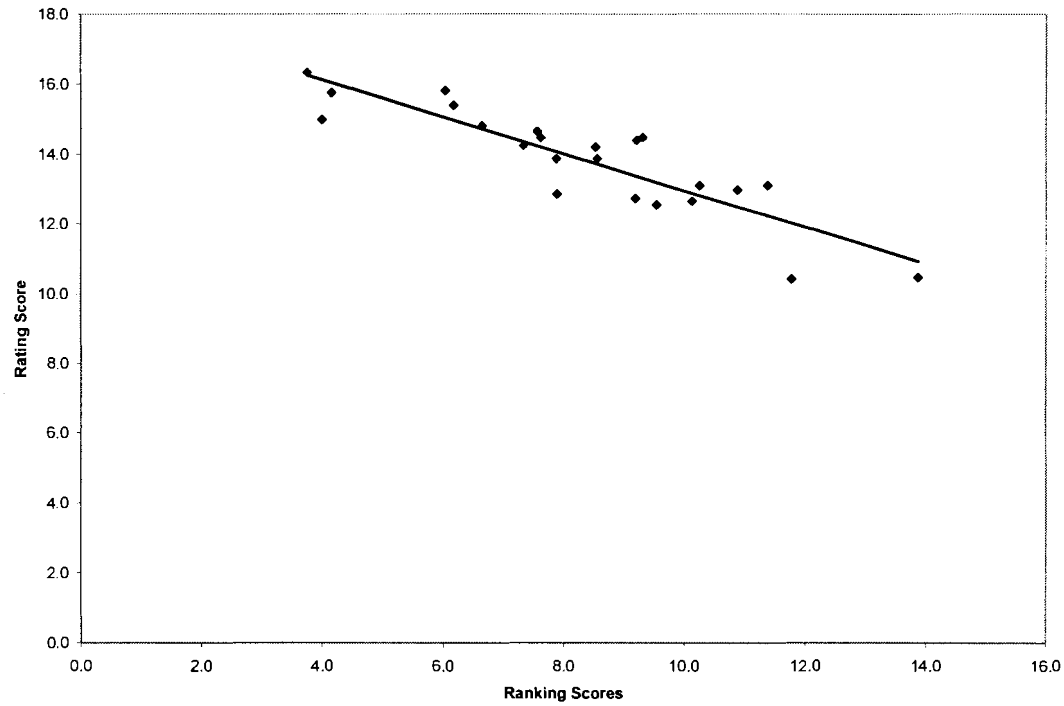

Figure 16. Scatterplot of mean ranking scores and mean rating scores

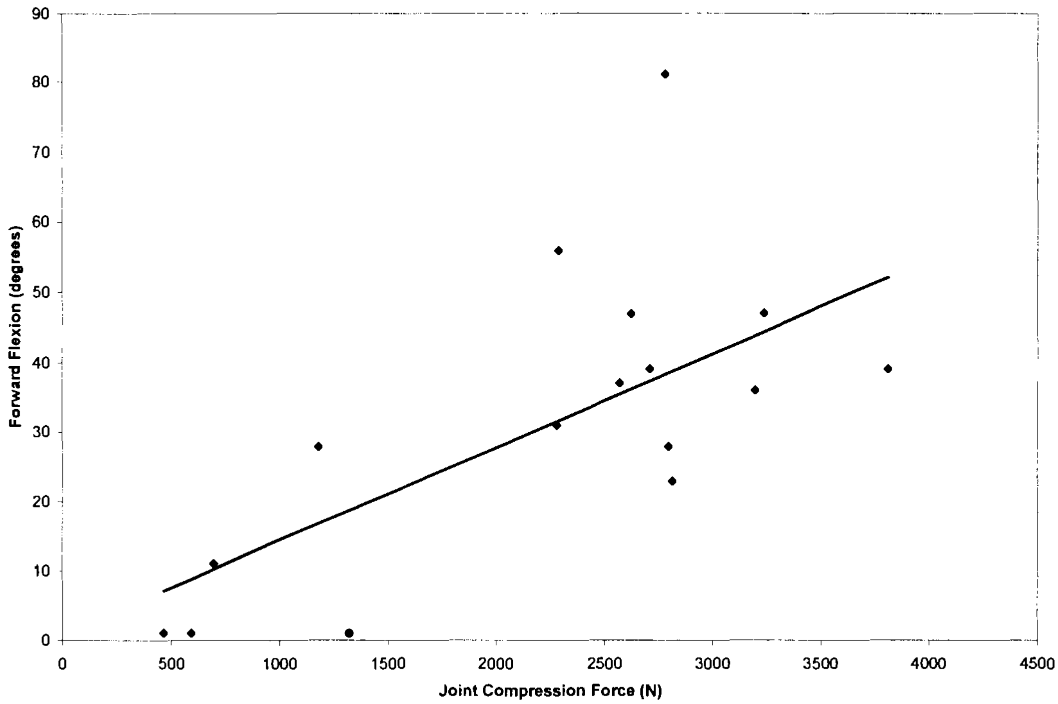

Figure 17. Scatterplot of forward flexion and joint compression

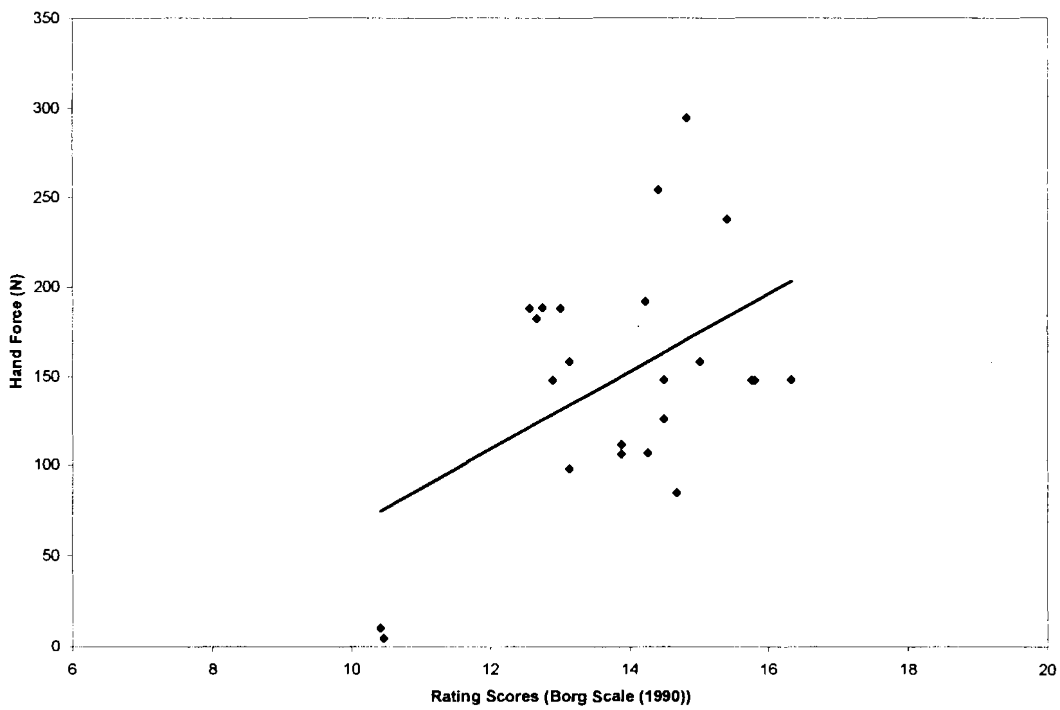

Figure 18. Scatterplot of hand force and mean rating scores

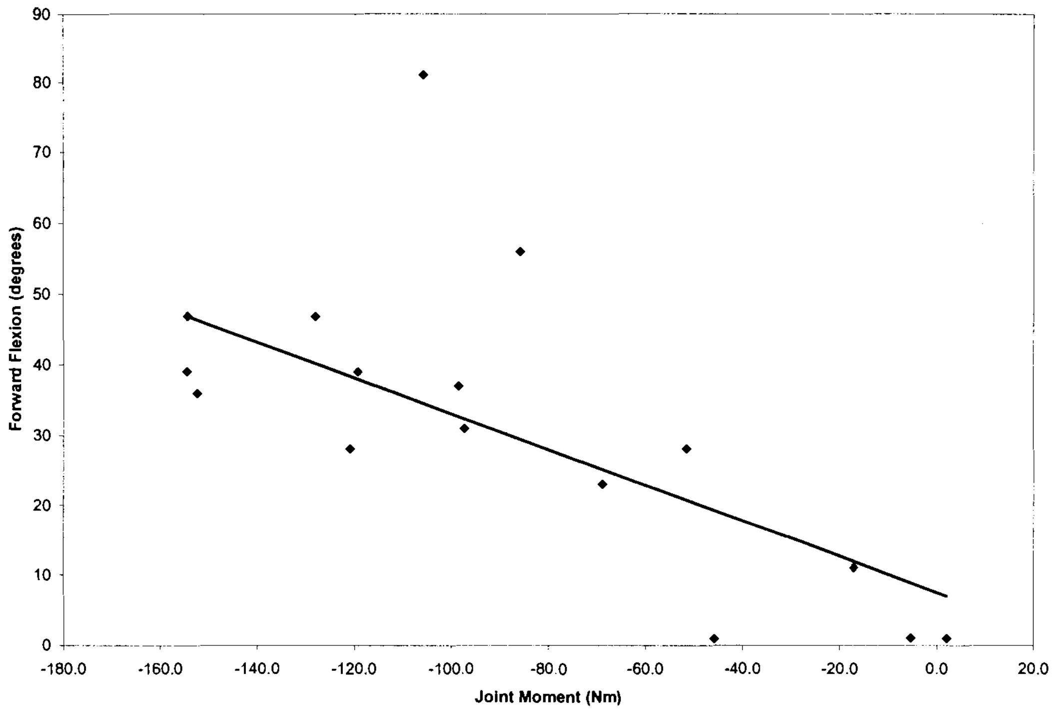

Figure 19. Scatterplot of forward flexion and joint moment

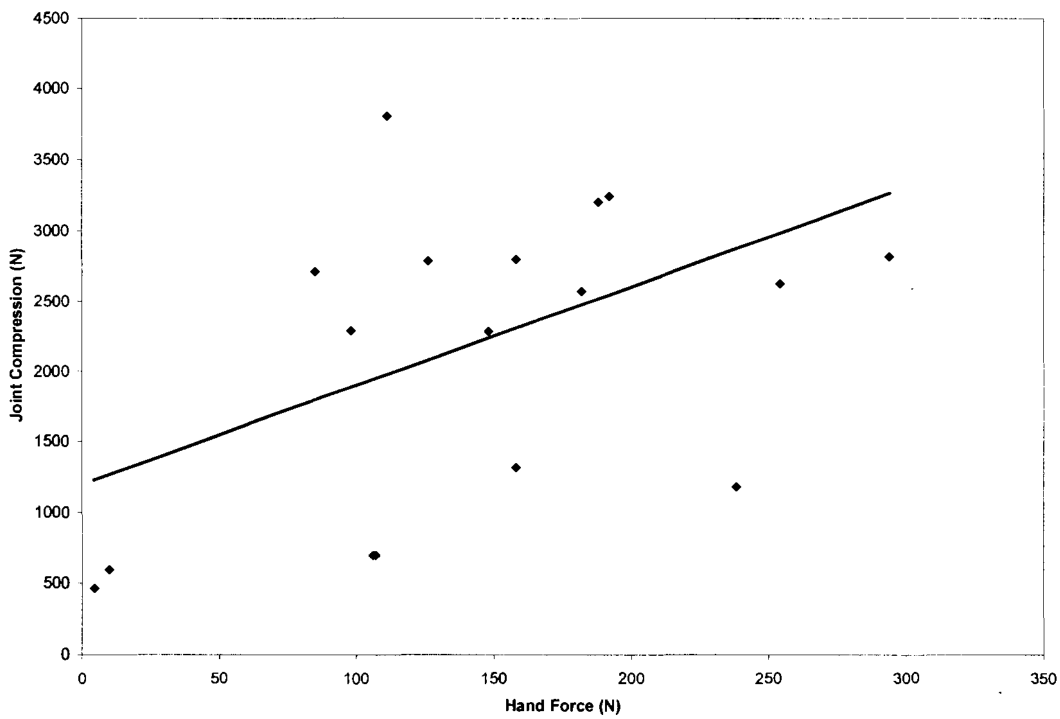

Figure 20. Scatterplot of compression and hand force

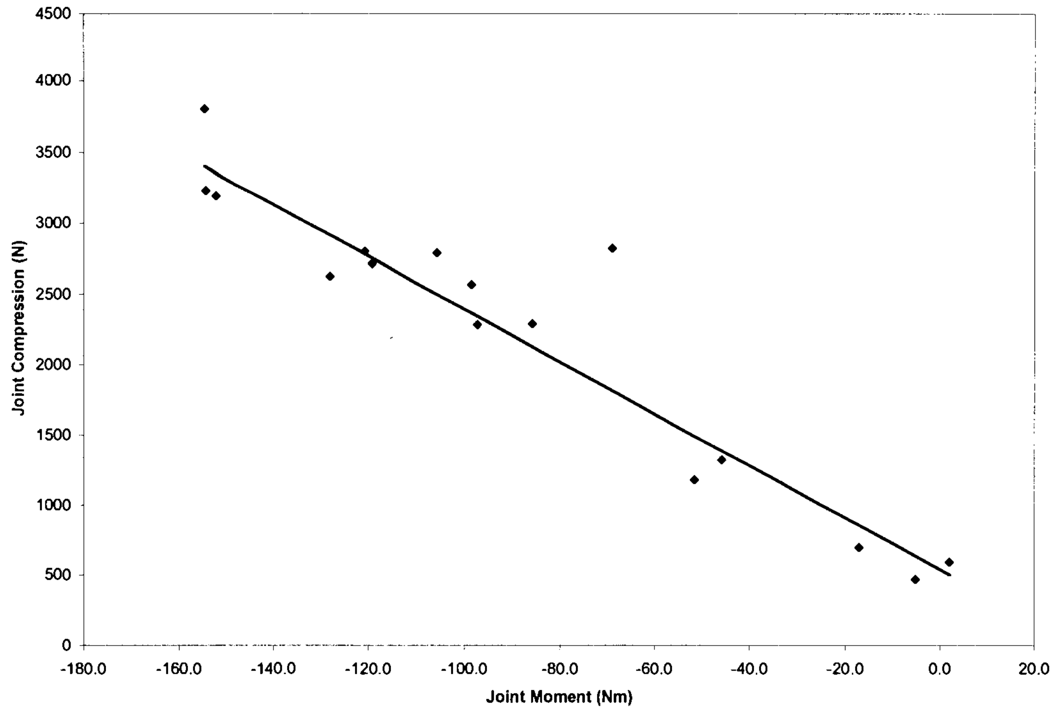

Figure 21. Scatterplot of compression and joint moment

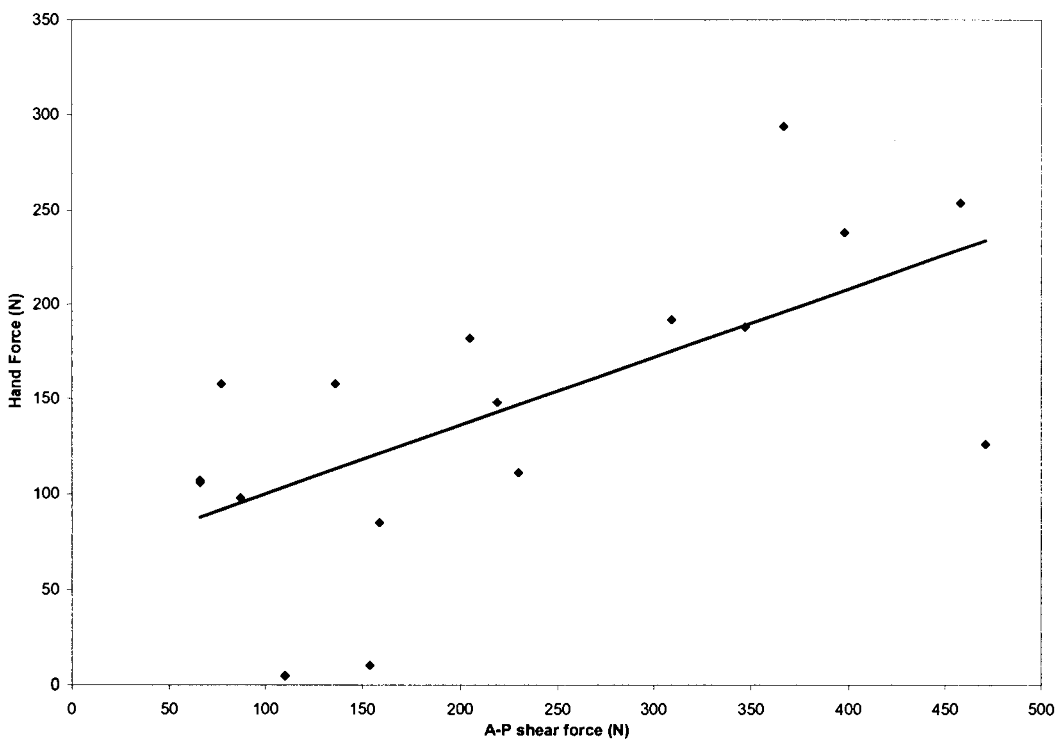

Figure 22. Scatterplot of hand force and A-P shear force

Discussion

Given their high Pearson correlation coefficient, ranking and rating scores tend to provide the same level of information in terms of task severity. However, neither variable is well correlated with any of the biomechanical measures at the low back: compression, shear or moment at L4/L5. The current study suggests that in the healthcare industry, subjective measures of risk may not reflect the risk presented by biomechanical loading at the low back for patient handling tasks. The absence of significant correlations between the subjective and the majority of objective measures was unexpected. It has been shown in previous research that subjective indicators of risk are well correlated with objective measures for simple manual tasks (Asfour *et al.* 1983, Waters *et al.* 1993), as well as in patient handling tasks (Garg *et al.* 1992, Owen *et al.* 1992). However, an absence of relationship between subjective and objective measures for manual materials handling was reported by Waikar *et al.* (1991).

Based on the weak correlations between the subjective and objective data, subjective measures do not provide clear indications of the presence of biomechanical risk factors for low back injury. As such, it may be inappropriate to use subjective measures as indicators of the presence of, or changes in levels of risk in a residential care environment. Biomechanical factors remain the objective measures of risk of low back injury in this workplace, due to in part the considerable volume of research identifying the role of peak and cumulative lumbar joint forces and moments in the likelihood of low back injury development (Kumar 1990, Norman *et al.* 1998), as well as the findings of high levels of compression in previous studies performed in the healthcare environment (Skotte *et al.* 2002, Schybye *et al.* 2003, Zhuang *et al.* 1999, Marras *et al.* 1999, Daynard *et al.* 2001).

The statistically significant relationship with peak hand force identified in the current study does provide some indication that subjects take into account the forces at the hands when they consider the level of stress or level of exertion they experience during task performance, but the correlation between these two measures was not strong with hand force explaining less than 19% of the variance in the rating values.

Using methods similar to those used by Owen *et al.* (1992), the values for each subjective and objective variable were converted to rank scores. As shown in Table 21, the subsequent correlation analysis failed to identify any additional significant relationships among the variables, instead producing a non-significant relationship for the only significant subjective-objective relationship identified in the previous actual value correlation analysis (between rating and hand force). Given the results of this analysis, it appears that ranking the variables prior to determining correlations provides limited additional value with respect to the workers' perceptions of stresses and exertions in their work environment and their relationship with objective measures of biomechanical joint forces. Hence, the results shown by Owen *et al.* (1992) were not reproduced.

There are a number of possible reasons for the absence of significant correlation between the subjective measures and the objective measures of joint force and joint moment. The lack of consistent findings between the current study and the study published by Owen *et al.* (1992) could be explained by the difference in force data used in the biomechanical analysis. The study performed by Owen *et al.* (1992) assumed a force value of one-half the mean resident's body weight for a two-person transfer task, whereas the current study used hand forces that were either directly measured during task performance or through force replication performed immediately following task performance. This difference in force measurement methods could account for the differences in the mean compression scores reported in both studies.

A number of tasks that were rated as highly stressful and given high Borg scores were tasks that take longer to complete (a few minutes versus a few seconds); duration of the task could be a factor, or more specifically, static contraction levels at the low back sustained during prolonged forward flexion. The subjects could perceive risk as a function of physiological creep in the viscoelastic properties of the discs, or as a function of muscle fatigue, instead of the peak forces acting within the spine.

Other contributors could be the role of resident factors as manifested during the performance of resident care tasks. Interviews with the workers revealed that they often cite the resident's uncooperative behaviour as a risk for low back injury. It was not possible to simulate this type of event during the focus groups and biomechanical analysis. In a separate analysis, it was found that aggressive and resistive behaviours occurred more frequently during personal care tasks, such as dressing in bed, bathing or am/pm care (Smith *et al.* 2000). Workers in focus groups also reported difficulties with very contracted residents, which increased the level of difficulty for tasks such as bathing and dressing. Other factors that may confound the data include perceived pressure from families to complete tasks in a rushed manner, or difficulties in working with co-workers or other groups on the care unit. Additional details on these factors are described in Study I.

Low correlations between joint forces and moments and subjective measures of risk may also be a reflection of two additional features observed in the data: most of the tasks rated by workers fell within a fairly narrow range of the Borg scale (12-16), thus making positive correlations with other variables difficult to identify. The joint compression forces calculated in many of the tasks were similar in value, to an extent that would render it difficult for subjects to differentiate the level of subjective stress among tasks. For example, 16 of the 23 tasks had a joint compression force within the range of 2280N to 3240N, and several tasks identified the same activity (i.e., same sub-task) as being the most stressful part of the task.

In summary, the weak correlations could be a result of the multifactorial nature of low back injury development noted by Marras (2000) and Kumar (2001), and the contributing factors described above.

Conclusions

With the exception of hand force and rating, there were no significant correlations between the subjective and objective measures examined in this study. This result was unexpected and requires further research to identify the factors influencing the measures of subjective ratings of resident care tasks.

Subjective measures of low back injury risk obtained in a healthcare setting are likely to include considerations other than force, which may or may not include aggressive or resistive resident behaviour, unpredictable behaviour of the resident, relationships with their co-workers, perceived pressures to complete work, the time spent in forward flexed postures, or the total task duration. Further study is required to examine these relationships.

Subjective measures of rating tasks for physical effort are correlated with measures of hand force. Hand force, however, explains less than 19% of the variance seen in the subjective data. This relationship, along with the similar relationship between ranking stress and hand force, warrants further examination in a paired analysis study of subjective perceptions of effort immediately following measures of hand force. Additional data that could be collected may include duration of postures held during task performance as well as total task duration.

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STUDY IV: MODELING CUMULATIVE LOADS FOR PREDICTING PROBABILITY OF LOW BACK INJURY

Abstract

The ability to predict probability of low back injury in the workforce based on measures of work exposure to manual handling tasks is unavailable in the ergonomics literature. Some models provide the likelihood of workers' membership in a "low back pain" group, while others predict the percentile of the workforce that can perform the work safely. However, none of the injury models available predict the cumulative injury incidence (over time) expected from a specific work environment, and none are based on the patient handling tasks commonly encountered in the health care industry.

In this study, a low back injury model was developed that uses material fatigue theory to predict the onset of low back injury in residential care workers as a result of cumulative loading of vertebral tissues. The model's inputs are the peak L4/L5 lumbar joint compressive loading calculated in each task and the frequencies of task performance in residential care environments. Data from the literature were used to determine the relationship between ultimate strength, cyclic loading and strength at failure of the lumbar spine. Low back injury data obtained from workplace records over a five-year period were used to obtain actual injury incidence rates as a function of work exposure for a period of up to five years. These data were used to adjust model parameters in order to obtain a best fit prediction of injury. A cumulative probability distribution curve was generated from the model output to illustrate the behaviour of injury development over a full time working career. The fatigue model predicts that 50% of residential care workers will experience a low back injury by their eighth year of work experience, and 95% by their fifteenth year of work.

The adjusted ultimate strength value of the L4/L5 joint derived from the best fit model, based on actual injury data, was found to be somewhat higher than that predicted from cadaver data in the literature. This may be due to an underestimation of in-vivo ultimate strength based on data obtained from in-vitro testing of cadaver specimens; it may reflect a degree of self selection among the workforce, or other factors. It is concluded that, while this model provides a good prediction of injury risk in residential care workers, the model needs to be further refined to incorporate: more comprehensive low back injury data, confounding factors such as shear loading, and viscoelastic (creep) effects on lumbar joint strength, and an improved biomechanical data base for in-vivo material properties of the lumbar spine.

Introduction

Cumulative loading at the low back has been examined as a factor in the onset of low back pain. Kumar (1990) and Norman *et al.* (1998) have looked at the differences in cumulative loading in workers with and without low back pain. Both studies found that workers with low back pain had significantly higher cumulative load values. Although these two studies used slightly different methods for calculating cumulative loading, they both assumed cumulative loading to be the product of load and time. However, this method of calculating cumulative load does not reflect the load deformation or material failure characteristics of tissue. Norman *et al.* (1998) also identified peak spinal loads, trunk motion, and external hand forces as variables that distinguish cases with low back pain from controls. Kumar (2001) proposed four different theories of injury: multivariate interaction theory, differential fatigue theory, overexertion theory and cumulative load theory.

In order to explain the onset of low back injury (LBI) due to repetitive loading, a material fatigue model has been proposed by a number of researchers (Payne 1992, Sandover 1986, Morrison *et al.* 1997, 1999). This model assumes that the onset of trauma in tissue results from the cumulative exposure, or "dose", and that failure can be defined as a function of the peak load and the number of cycles (or repetitions). This model has its foundations in material fatigue theory (Miner 1945), which describes the ability of a material to tolerate repeated loading.

A number of studies have reported the relationship between repeated loading and fatigue failure of biological tissues (Sandover 1983, Hansson *et al.*

1987, van Dieen & Toussaint 1997, Zioupos *et al.* 2001). Sandover (1983) proposed two mechanisms of fatigue failure regarding cumulative loading in low back disorders: 1) that cumulative axial loading leads to damage to the vertebral end-plate, which affects the nutrition of the intervertebral disc, and 2) that dynamic shear, bending and rotational loading leads to the breakdown of the annular tissues of the intervertebral discs.

Morrison *et al.* (1997, 1999) have used this approach to assess the hazard of LBI in operators of military ground vehicles. Through biomechanical analysis of lumbar joint loading and using a fatigue failure model, the researchers proposed a method of LBI risk assessment when military personnel are exposed to repeated mechanical shocks. This fatigue failure approach to LBI has been further developed into an international standard for assessment of repeated impact in humans (ISO 2004). A similar approach may be applicable to evaluating the risk of LBI from repetitive spinal loading associated with patient handling. Although other mechanisms for injury have been proposed (Kumar 2001, Norman *et al.* 1998, Marras 2000), this study will investigate a fatigue failure model as a predictor of low back injury.

Methods

Model of Fatigue Failure

It has been shown that any tissue subjected to a repetitive load (F) at a level below the ultimate strength (F_u) will eventually fail. The number of cycles (N) to failure can be described by the equation:

$$N = (F_{\mu}/F)^x \qquad \text{Equation 1}$$

where *x* is an exponent that is characteristic for the tissue of interest.

The degree of fatigue due to repetitive loading can be defined in terms of the number of cycles (n) applied at a given load, F, and is shown by the equation:

$$D = (n/N) \qquad \text{Equation 2}$$

where *D* is the fraction of fatigue life consumed and *N* is the number of cycles to failure at a give load. Thus, when n equals N, then D equals 1, and the tissue reaches failure.

Similarly, if a number of cycles at different loads (i = 1,...k) are applied to the tissue, the degree of fatigue can be represented as:

$$D = (n_1/N_1 + n_2/N_2 + \ldots n_k/N_k) \text{ or, } D = \Sigma(n_i/N_i) \qquad \text{Equation 3}$$

By combining equations 1 and 3, it can be shown that fatigue can also be represented as an equivalent single static load, or stress level over a number of tasks (Sandover 1986, Payne 1992, Morrison *et al.* 1999):

$$F_e = \{\Sigma[n_i(F_i)^x]\}^{1/x} \qquad \text{Equation 4}$$

where F_e is the single static load which is equivalent to the repetitive loads (n_i, F_i) applied to the tissue. Thus, F_e can be considered to be the single load which will produce the same degree of fatigue, D, in a material as a specified number, n_i, of repeated loads of value F_i.

The stress dose can then be calculated as:

$$D_s = F_e/F_\mu$$

$$= (1/F_\mu)(\{\Sigma[n_i(F_i)^x]\}^{1/x}) \qquad \text{Equation 5}$$

Ultimate compressive strength (F_μ) of spinal motion segments have been reported to be between 2000N and 12000N for a variety of study populations of mixed gender and age (Hansson *et al.* 1980, Hutton & Adams 1982, Porter *et al.* 1989, Brinckmann *et al.* 1989). The ultimate compressive strength ($F_{\mu f}$) and variance ($SD_{\mu f}$) for the L4/L5 vertebral motion segment will be calculated for this worker population as an input into the model.

The values for "x" for different biological tissues have been reported to range from 5 to 20 (Carter *et al.* 1981, Lafferty 1978, Sandover 1986) with low values representing bone and higher values representing ligament. One study which has examined the fatigue behaviour of in-vitro vertebral motion segments calculated "x" to be 13.54 with a correlation of r = 0.7 (Hansson *et al.* 1987). However, previous fatigue dose models have utilized more conservative values of "x" of 6 to 8 (Payne 1992, Morrison *et al.* 1999, ISO 2004). For the purposes of this study, an exponent of 13.54 will be used.

The peak compressive forces for each critical task are obtained from the biomechanical analysis conducted in Study II (F_1, F_2, F_3, F_4 ...). The task frequencies (n_1, n_2, n_3, n_4...) are obtained from the focus group data in Study I.

An addition factor is included to account for each year of work experience (y_1, y_2, y_3, y_4...). These variables can be introduced into the model to give:

$$F_e = [y_1 n_1 (F_1)^x + y_2 n_2 (F_2)^x + \ldots]^{1/x} \qquad \text{Equation 6}$$

$$\text{Or: } F_e = \{\Sigma[y_i n_i (F_i)^x]\}^{1/x} \qquad \text{Equation 7}$$

The equivalent static load F_e can then be compared with the ultimate strength of the L4/L5 lumbar segment to determine the risk of LBI. Assuming a normal distribution for ultimate strength ($F_{\mu f}$), the cumulative risk of injury (P_{LBI}) can be determined for any year of work experience as a function of F_e, $F_{\mu f}$, and $SD_{\mu f}$ of the form (Morrison *et al.* 1997):

$$P_{LBI} = f\,[(F_e - F_{\mu f})/SD_{\mu f}] \qquad \text{Equation 8}$$

Where, $F_{\mu f}$ and $SD_{\mu f}$ are the mean and standard deviation of ultimate strength for the worker population, respectively.

In order to utilize the model described above, it is necessary to determine the model parameters. These include the task frequencies, the peak compressive loading of each task, the mean and standard deviation of ultimate compressive strength of a female spinal motion segment, and the fatigue exponent. In order to refine the model to obtain a best fit to the worker population, it is necessary to have the knowledge of the "first time LBI" incidence as a function of cumulative exposure. This can be expressed in the form of cumulative "first time LBI" rates per year of work experience.

Task Frequencies

Study I assembled focus groups in six different residential care units with eight voluntary worker participants in each group. Each focus group was asked to develop a list of the most physically demanding tasks in their regular work routine. Focus group members were asked to identify the average number of times they would perform a task in a typical shift, providing task frequencies. Frequency data were collected from each worker in each focus group and processed to provide mean and standard deviation values across tasks.

Biomechanical Data

Study II asked the workers in the same focus groups to demonstrate the part of the task that they identified to be the most difficult. The group arrived at a consensus as to the method used for the task as well as the portion of the task that was to be modeled. The task was performed by each worker as a subject, with one worker volunteering to act as a resident appropriate to the type of task being modeled (i.e., a resident requiring a 2-person pivot transfer will be more physically dependent than a resident appropriate for a 1-person pivot transfer). Task performance was captured using two digital video devices, one obtaining a sagittal image and the other obtaining a coronal image. Hand force values were captured using either direct measure or force replication methods.

The subject height, mass and hand force values for each trial were analysed for each task to obtain the population mean and the root-mean-square (rms) differences from the mean for each of the values for each trial. The trial with the lowest average rms value was selected to be the most representative trial for that task.

The video images from the representative trial were downloaded onto a computer using video editing software and the frame representing the part of the task with the greatest level of difficulty and worst posture was captured. This provided two images for each task, one from each camera. These images were then used as references by the investigator when modeling the posture in a packaged biomechanical analysis software program (3DSSP, University of Michigan, 2003). The hand force, subject height and mass were inputs into the model, and the hand force direction was established using the video data as a reference. The outputs of this biomechanical analysis provided the compression force at the spinal level of L4/L5 for each task modeled by the focus group. This analysis provided an array of peak compressive force values (F_i) required as input to the fatigue failure model.

Ultimate compressive strength (UCS)

The literature was examined to determine the ultimate compressive strengths used by other researchers in determining safe lifting limits. Waters *et al.* (1993) referenced published data indicating ranges in ultimate compressive strength from 2.1kN to 9.6kN. Another study cited by Waters *et al.* (1993) demonstrated a mean ultimate compressive strength of 4.4kN with a standard deviation of 1.88kN. Waters *et al.* indicated that one of the limitations of this data is whether or not cadaver studies examining strength of the vertebral tissues in-vitro are accurate indicators of the strength of the tissues in-vivo. This concern was also raised by Wall *et al.* (1970) in their examination of the variability of data obtained from human bone strength tests. They reported a number of variables that affect the results of bone strength tests, including the extraction and preparation of the bone sample, the storage conditions of the sample, the time lag between when the sample was taken and the test, and the machinery used to test the sample. If these and other variables are not controlled for across studies, it becomes difficult to accurately compare the results among the range of studies available. Ultimately, Waters *et al.* (1993) recommended that the biomechanical limit used by the NIOSH equation be based on data that established the relationships between increasing compressive forces found in the work environment and increased reporting of low back disorders.

Waters *et al.* (1993) acknowledged the possibility that age and gender likely affect the ultimate compressive strength of the vertebral tissues. Genaidy *et al.* (1993) pursued this line of inquiry and examined the published cadaver data to determine the relationships between ultimate compressive strength and individual characteristics such as age, gender, spinal level, and body mass of the subject from which the sample is taken. The authors utilized a number of data sources on failure strength of vertebral spinal units (two adjacent vertebrae with the intervertebral disc, along with the ligamentous structures and posterior spinal elements), vertebrae and intervertebral discs. They analyzed the data to examine the effects of age, gender, spinal level and body mass. They developed a regression equation that incorporates factors for each of the above variables:

$$CS = -13331.2-(73.7*AGE)-(962.6*GENDER)+(403*LMS)+(79.8*BW)$$

where

CS	= compressive strength (N);
AGE	= age (years);
GENDER	= gender (male = 1; female = 2);
LMS	= lumbar motion segment of interest (L4-L5=47);
BW	= body mass (kg);
R^2	= 0.4828

The above equation was used to modify the mean UCS used in the fatigue model ($F_{\mu f}$ in Equation 8) on an iterative basis according to the mean age at the date of hire of the average worker and the years of work experience. Attempts were also made to ensure the standard deviation ($SD_{\mu f}$) within the values of the dummy data was equivalent to approximately 20% of the mean UCS, similar to the assumption used by Morrison *et al.* (1997), based on data published by Hansson *et al.* (1987).

Injury Data

Study I also provided injury data for the worker population. These data were extracted from an employer's injury database for a five year period. These data were filtered to include only low back injuries, and then further processing was performed to exclude all repeated low back injuries within the five year period.

Further refinement of the injury data was performed to determine the actual cumulative rates of low back injury. This involved the knowledge of employee turnover, the number of shifts worked in a typical full time year, the inclusion of some previously excluded injury data for the purposes of modeling and a correction for previous injury data missing from the cross-sectional injury data set obtained from the employer. Values for worker turnover and number of worked shifts in a calendar year were obtained from personal consultations with a human resources consultant within the healthcare organization.

Injury Data Adjustments

Injury data from Study I were analysed in order to determine annual injury rates according to years of work experience. Injury rate calculations were based on a number of assumptions about the worker population. It was assumed that the number of workers employed in each work unit did not fluctuate significantly over the five year period from which the injury data was taken. Discussions with human resource personnel confirmed that there were few if any program changes in the study units during the years from which injury data were extracted. In addition, hiring practices indicate a relatively stable number of employees within any one work unit over the same period. The second assumption is that the hiring rate over the five year period reflects the turnover rate for the worker population. In conversations with human resource consultants, this assumption appears to have some basis in observed practice, although the human resources department is unable to access this type of historical data.

The number of shifts worked by a full time worker was provided by the human resources department. During the time period from which the injury data were obtained, the full time work is defined as 1879.2 hours worked per year. Using 7.2 hours per shift, and subtracting 11 statutory holidays and 20 vacation days per year, the resultant number of shifts worked each year by a full time worker is 230.

In addition, the human resources department is unable to provide statistics to indicate the average number of shifts worked by a typical part time or casual worker in a given year, making it difficult to assume the number of shifts each part time or casual worker worked each year. Part time positions can vary in their shift allotment depending on the unit's shift schedule. Part time positions can be 0.5, 0.3, 0.71 or any other proportion of full time work depending on the needs and preferences of the unit. It is also found that some casual workers may work in excess of the equivalent of full time work as they are able to work for multiple employers. Both full time and part time workers are able to work overtime shifts, thus exceeding their allotment of assigned shifts for their position. In the absence of better data, it is assumed that each injured worker in the data set worked the number of shifts equivalent to full time work in each year of their work experience.

Using the "years of work experience at time of injury" variable, all injury records were grouped according to the year of work experience in which the injury occurred. This provided the incidence of LBIs by year of work experience. The data were adjusted to include data points that were originally excluded from the data set due to lack of "date of hire" data (absence of "date of hire" was due to the employee's termination). This was achieved by increasing the number of LBI incidents for each year of work experience by 17.6%, equivalent to the proportion of data that were originally excluded.

The corrected data then provided the number of LBIs (n=220), the total number of "first recorded LBIs" (n=159) and the number of "repeat LBIs" (n=61) recorded over five calendar years. Using the complete data set, the rate of "repeat LBIs" per annum was calculated. From the resultant injury data analysed over the five year period, it was clear that there is a high incidence of re-injury among the workforce. Therefore it is not practical to use the complete data set to provide a best fit to the fatigue failure model developed in this study. It is likely that some of the LBIs recorded by workers with more than five years work experience are "repeat LBIs" rather than "first time LBIs". For this reason, only the data of workers with five years of work experience or less is used in obtaining a best fit to the model.

A further adjustment was made to the first five years of injury data to correct for any repeat LBIs from previous years that were not accounted for in the data set. A separate correction was applied to injury data for each year of work experience. As the historical data for these workers were available for most years, only a minor correction was required to the "first recorded LBI" data.

These corrections determined the "first time LBI" injury rate for each year of work experience. Each year's injury rate was then added to the previous to create a cumulative LBI count for up to five years work experience. The cumulative "first time LBI" data were used to refine model performance.

Fatigue Model Parameters

The mean task frequency and representative joint compression force for each task were entered into a spreadsheet (Microsoft® Excel 2002, USA) as inputs into the model. The number of worked shifts for a full-time worker (230 shifts) was entered into an equation to calculate a new variable for each task: "frequency of task per year". This value was used in Equation 7:

$$F_e = \{\Sigma[y_i n_i (F_i)^x]\}^{1/x} \qquad \text{Equation 7}$$

where y_i is the number of years of work experience, n_i is frequency of task per year for task i, F_i is the representative compression for task i, x=13.54 (taken from Hansson *et al.* 1987), and F_e is the single equivalent load dose for a given number of years of work experience.

A dose array was developed, which provided the value of F_e for each year of work experience. The array ran from one year to 31 years of work experience, to represent the average worker who started at age 34 (the mean age on date of hire for workers, determined in Study I) and worked to retirement at age 65.

The five-year cumulative "first time LBI" incidence obtained from the injury data was used as a reference point for the model to obtain best fit to the injury data. The value of ultimate compressive strength used in the model was adjusted until the cumulative probability of LBI after five years of work experience closely matched the cumulative "first time LBI" incidence determined from the injury data. Then, using degradation factors determined by the equation of Genaidy *et al.* (1993), the ultimate compressive strength at each year was degraded to account for the age-related strength changes in UCS.

The resultant UCS values, along with values of F_e for each year of work experience, were used in Equation 8 to calculate the cumulative probability of LBI.

The equation published by Genaidy *et al.* (1993) was also used to calculate ultimate compressive strength for the worker population, and used as a comparison to the UCS value used in the model to best fit the injury data.

Results

Determining Task Frequencies and Biomechanical Loads

The task frequencies obtained from the focus groups and joint compression forces at L4/L5 calculated in the biomechanical analysis are listed for each task in Table 22.

The shift frequency for a full time worker was determined to be 230 shifts per year. This value was used to calculate first-year dose values for each task (F_{et}) using the following equation (based on Equation 4):

$$F_{et} = [n_i(F_i)^{13.54}]^{1/13.54} \qquad \text{Equation 9}$$

Annual dose values for each task (F_{et}) are listed in Table 22.

Table 22. Summary of task frequency and compression at L4/L5

Task	Mean Frequency (per shift)	Compression at L4/L5 (N)	Single equivalent load dose (F_{et}) in 1st year (N)
Positioning in bed	14.0	3239	5882.7
Toileting	6.0	3196	5449.2
Sitting to standing	5.1	3196	5388.2
1-P transfer	4.4	3196	5324.7
Manual lift from floor	0.3	3811	5255.6
Boosting in bed	12.6	2812	5067.3
Lying to sitting	6.2	2779	4749.1
Reposition in wheelchair	5.5	2622	4445.9
2-P transfer	4.0	2568	4254.2
Showering	0.9	2709	3999.7
Dressing in bed	8.3	2281	3984.7
Am/pm care	7.0	2281	3933.5
Washing in bathroom	4.2	2287	3798.6
Mechanical lift from floor	0.3	2793	3780.9
Stretcher bath	1.1	2281	3435.5
Bathing in tub	1.1	2281	3433.6
Bed bath	0.8	2281	3362.8
Turning in bed	14.3	1178	2142.5
Bowel care	2.1	1320	2085.3
Use of lifter	7.2	695	1201.7
Use of stander	4.1	695	1153.1
Assisted walking	1.9	592	925.7
Feeding	9.2	467	822.0

The annual dose value for one year of work experience, which includes all tasks, is calculated using Equation 7 and inserting the value of 13.54 for "x", as provided by Hansson *et al.* (1987):

$$F_e = \{\Sigma[y_i n_i (F_i)^{13.54}]\}^{1/13.54} \qquad \text{Equation 10}$$

Using Equation 10, the values of F_e were calculated for each year of work experience, thus providing a compression dose from the first year to the 31st year of work experience. This time frame represents the average start date (age 34, from Study I), and the conventional retirement age of 65. Figure 23 represents the trend of annual load doses over this time frame of work experience.

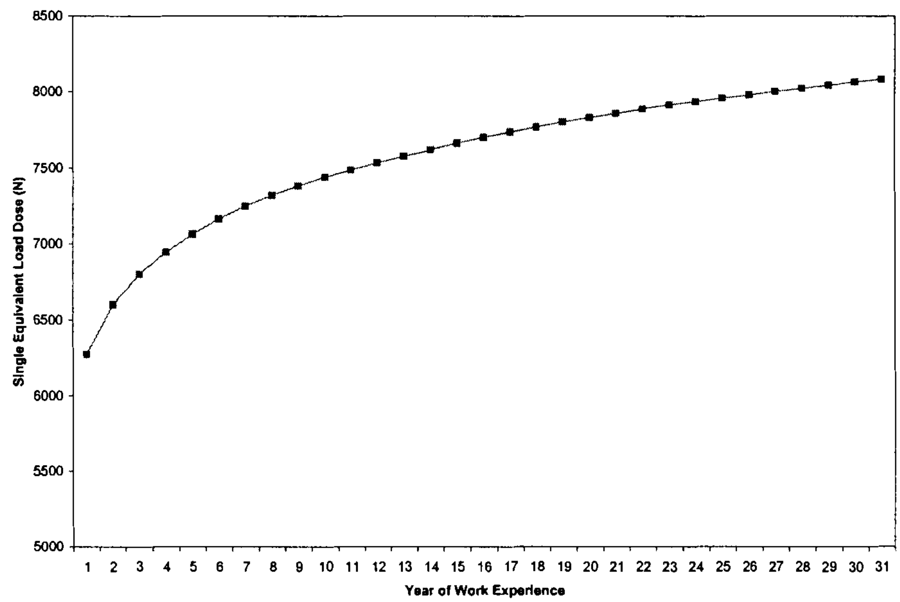

Figure 23. Cumulative dose over years of work experience

Injury Data

It is likely that workers who had been employed for more than five years experienced their first low back injury prior to the period covered by the injury database. Due to this potential confound, workers how had more than five years of work experience at time of first low back injury were eliminated from the "first time LBI" database. The injury data was filtered for only those records where the workers had five years or less of work experience at time of injury, a histogram of cumulative injury incidence was plotted in Figure 24.

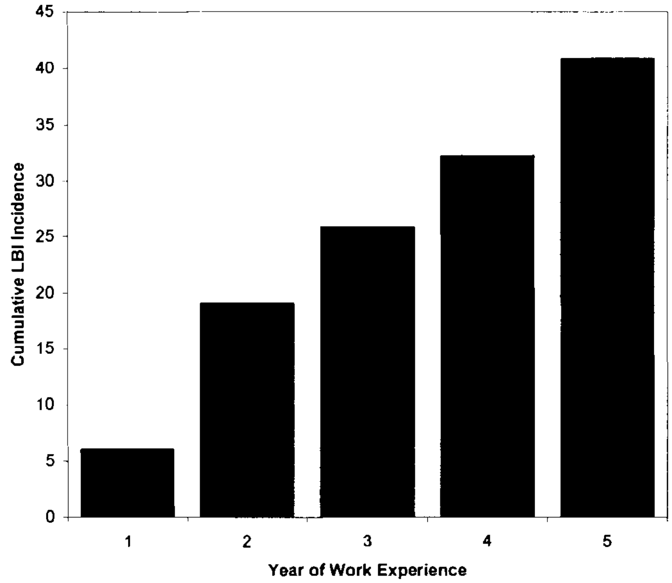

Figure 24. Cumulative number of low back injuries by years of work experience at time of injury (summed over five calendar years of injury records)

The total worker population within the facilities included in the injury data analysis totalled 578 workers. Data from the employer's human resources department indicated an annual recruitment rate of 6.25%, which also represents the annual turnover rate of the worker population employed in residential care. Using this rate, it was estimated the number of workers in their first year of work experience was 36. The population in each successive year of work experience was approximated by depreciating the number of workers by 0.0625 for year of work experience (see Table 23 below). The LBI rates for each year of work experience were calculated by dividing the number of LBI incidence by the estimated number of workers in that year. These figures are shown in Table 23. After five years of work experience, the cumulative injury rate was calculated to be approximately 26%.

Table 23. Injury rate values determined from injury data analysis

	Year of work experience				
	1	2	3	4	5
Average LBI incidence per year	1.2	2.6	1.4	1.3	1.7
Average number of workers remaining in each year of work experience	36.1	33.9	31.8	29.8	27.9
LBI rate for each year of work experience	3%	8%	4%	4%	6%
Cumulative LBI rate	3%	11%	15%	20%	26%

Development of UCS Data for Fatigue Model

Using the cumulative injury rate of 26% from the fifth year of work experience (see Table 23), the output of the fatigue model was adjusted. This was accomplished by modifying the mean value of UCS calculated for the fifth year in the fatigue model until the predicted probability of LBI closely matched the actual cumulative LBI rate of 26%, or 0.26. In the remaining years in the model, values of UCS are adjusted by 0.97% as described in the Methods, a rate determined by the equation from Genaidy *et al.* (1993). Table 24 lists the values of UCS used in the fatigue model, demonstrating the progressive decline in UCS as the worker ages.

Table 24. Values of ultimate compressive strength used in the fatigue injury model

Age	Ultimate Compressive Strength (N)
34	7714.2
35	7640.3
40	7280.2
45	6935.1
50	6606.4
55	6293.2
60	5994.9
65	5710.7

Fatigue Model Output

Probability of LBI in each year of work experience was calculated. This was achieved by performing a probability test for each year's calculated single equivalent load dose against the corresponding year's value of UCS, as described by Equation 8. The output of each test is a "p"-value representing the cumulative probability LBI for a worker.

Figure 25 shows the probability of LBI as a function of cumulative compression dose. The figure illustrates the increasing risk of LBI as the dose increases.

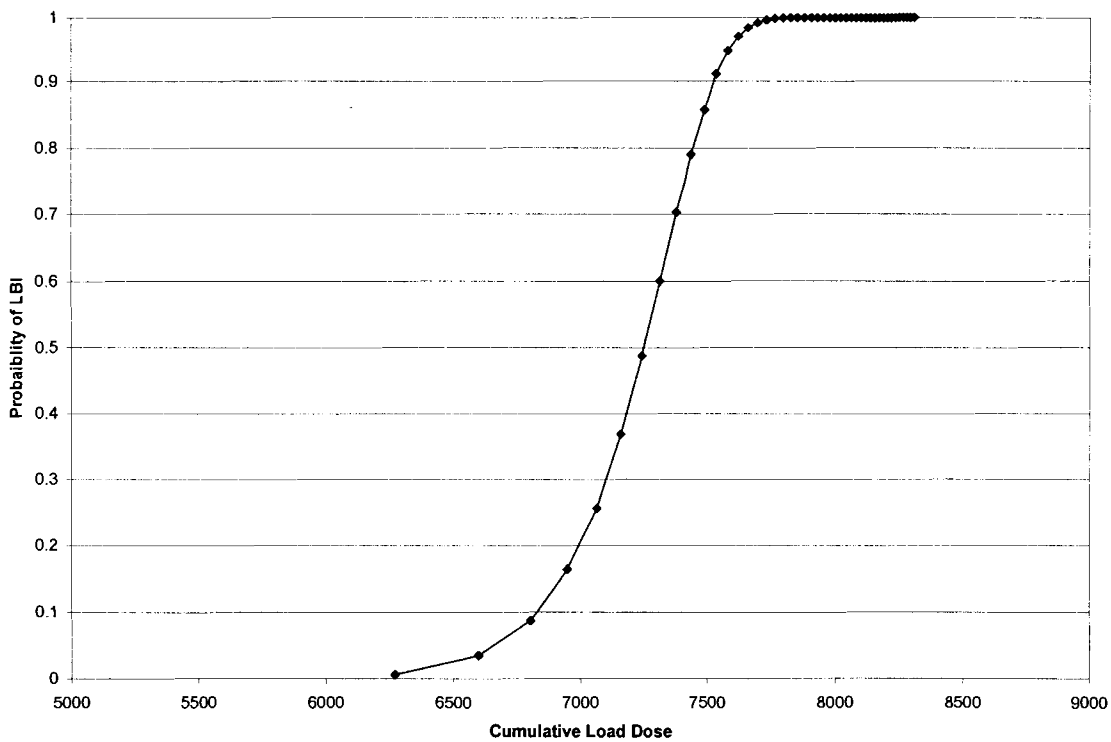

Figure 25. Probability of LBI as a function of cumulative dose

The individual points plotted in Figure 25 represent the increase in dose, and associated probability of LBI, in each successive year of work experience. Figure 25 demonstrates a slow initial increase in probability of LBI and a subsequent rapid rise in probability of LBI as the cumulative compression dose increases. The rate of change in probability does not slow until a high probability of injury is reached, indicating that the dose values have risen to well above the mean UCS value. The cumulative probability distribution does not follow the slope expected of a normal distribution function, particularly at the higher dose levels. The rapid increase in LBI probability as a function of dose is partly due to a corresponding decrease in UCS with age.

Figure 26 shows the increase in probability of LBI as a function of each additional year of work experience in residential care. The fatigue model output is plotted together with the calculated cumulative injury rates determined from the five years of LBI data available. Methods used to determine first-recorded LBI rates are described in the Methods section of this study.

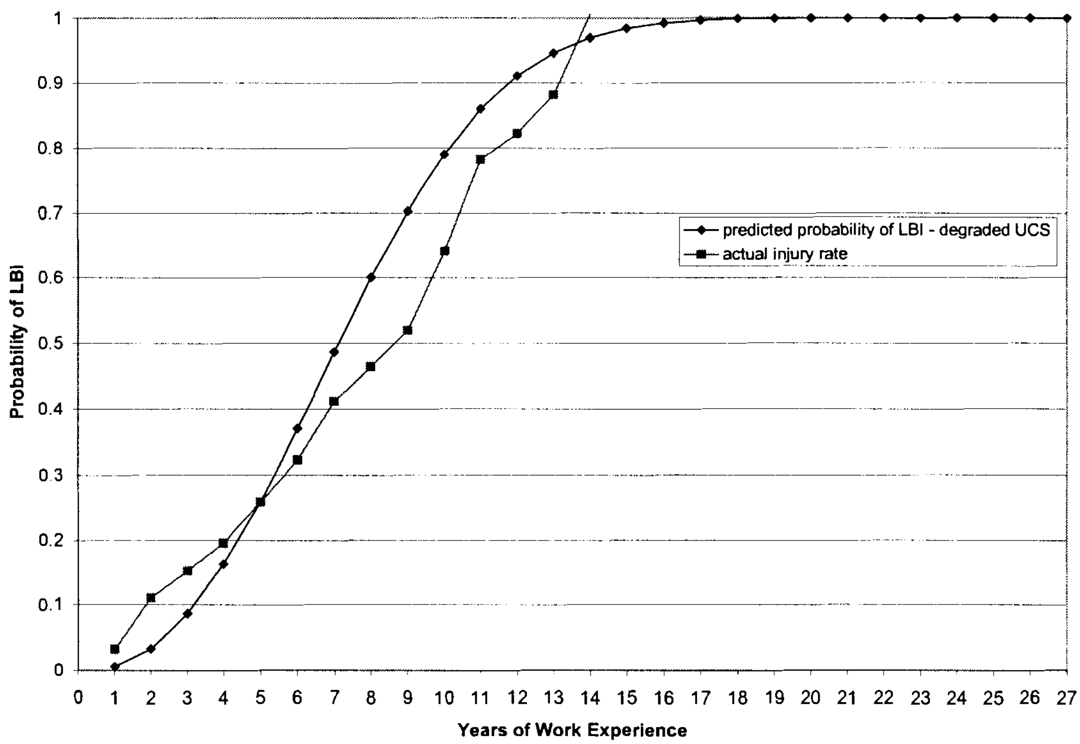

Figure 26. Plot of fatigue model illustrating cumulative probability of low back injury over years of work experience

The fatigue model predicts that 50% of the workers will experience LBI by their eighth year of work experience, and more than 95% of the workforce will experience LBI within 15 years of working in residential care. At the fifth year of work experience, it can be seen that the values of predicted probability of LBI and observed incidence rates of LBI are equal, representing the data point to which the model was anchored to obtain best fit.

Sensitivity Analysis

In order to determine the sensitivity of the fatigue model to the input data, two different analyses were performed: sensitivity to posture and sensitivity to hand force.

In the first analysis, the posture for each representative trial was modified by increasing and decreasing trunk flexion by 5°, providing two new compression forces for each task. Using these two compression values and the "normal" values used in the original model development, a random number generator was used to select one of the three values for compression for each task, developing a list of compression values with random errors due to possible errors in the postural analysis. These selected compression values for each task were used to re-run the fatigue model and plot a new graph. This process was repeated ten times to obtain ten different plots of predicted probability of low back injury with randomised error within the postural analysis of the tasks. These plots are shown in Figure 27, along with the plot of the original model.

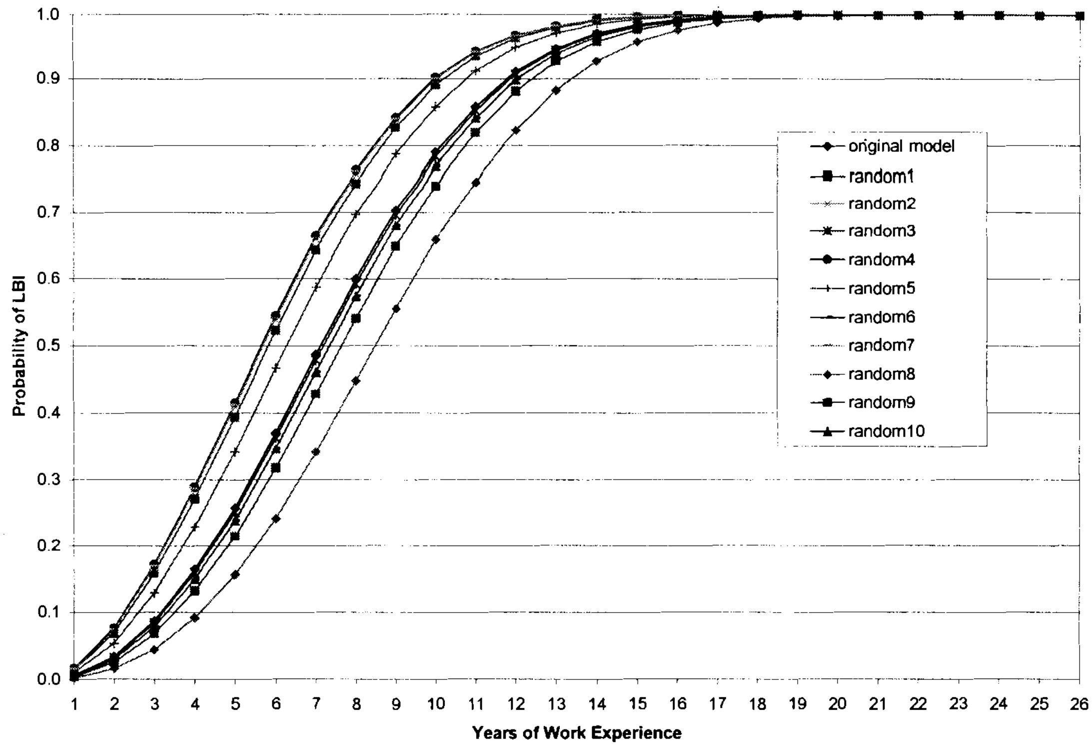

Figure 27. Plot of fatigue models with random error in posture analysis

The predicted values for each random error plot were compared to values in the original model to determine the degree and behaviour of randomised error due in posture analysis on the prediction of low back injury. The resulting differences in predictions are plotted in Figure 28 below.

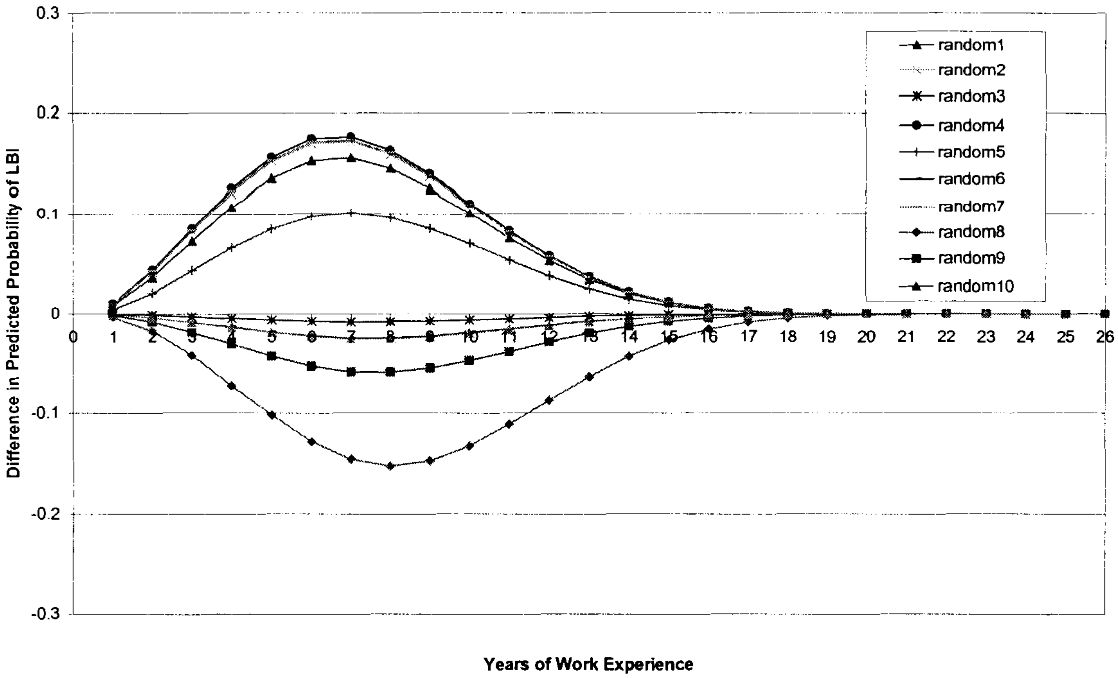

Figure 28. Error in prediction of LBI probability due to random error in postural analysis

The plot in Figure 28 demonstrates that most of the error in the fatigue model due to potential errors in the postural analysis is likely to occur in the years between four and ten years of work experience. This is a function of the low variance in the data in the early and later years. This behaviour is likely due to the low likelihood that any workers will be injured within the first year, and in the later years (>15 years), almost all the workers are likely to be injured.

Hand force replication is a recognised technique that has been used by other authors (Kumar 1990, Norman *et al.* 1998, Daynard *et al.* 2001) in assessment of biomechanical loading during in-field ergonomic research. Unfortunately none of these authors have reported accuracy of this technique. In this light, the second sensitivity analysis was undertaken to examine the effect of errors in estimations of hand force on the model output. As the input to the model is the mean hand force obtained from a sample of workers, the sensitivity analysis is based on an estimate of the standard error of the mean for each task.

The hand force sensitivity analysis was performed by modifying the hand force values for each task. The representative trial for each task was re-analysed with modified hand forces of values that were one standard error of the mean greater than and less than the "mean" values used in the original model. This provided two new sets of compression values for each task. The effect of errors in hand forces were then determined using methods identical to those used to analyse the effect of random error in the postural analysis on the performance of the fatigue model.

Figure 29 shows a plot of the fatigue model along with ten plots with random error due to hand force variation.

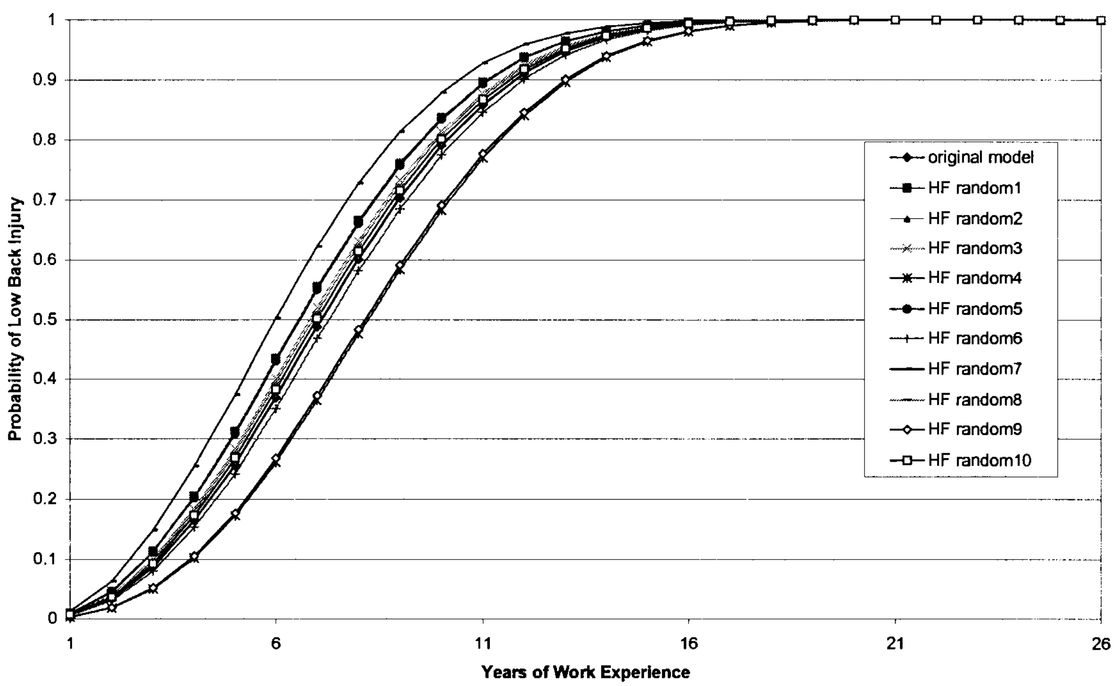

Figure 29. Plot of fatigue models with random error in hand force values

The difference in the random error plots and the original model are plotted in Figure 30.

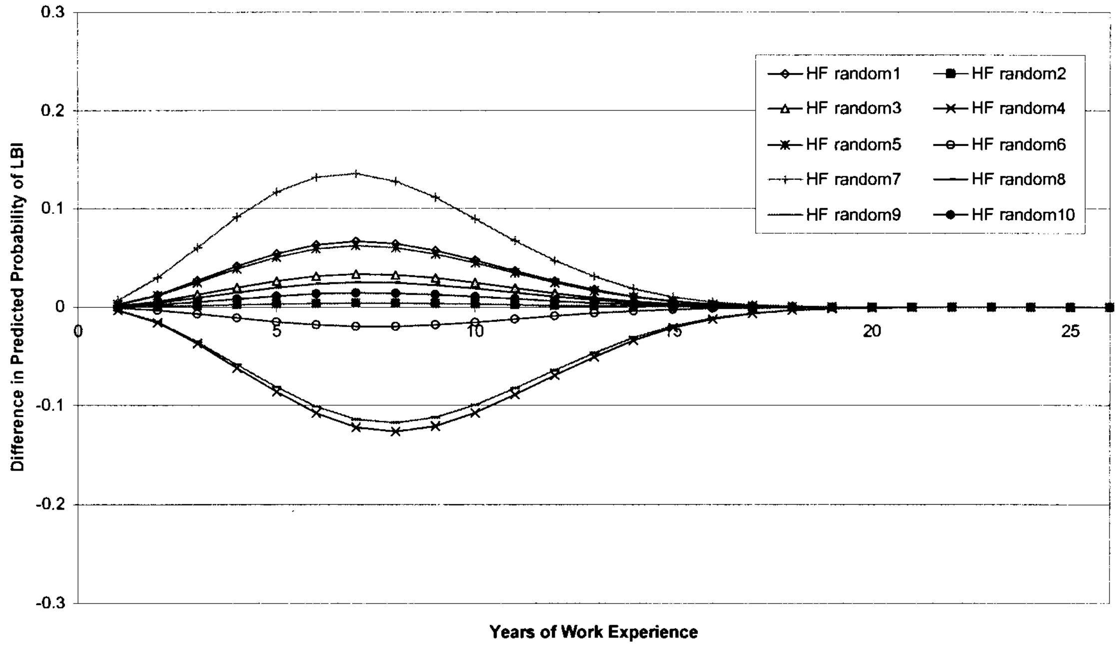

Figure 30. Error in prediction of LBI probability due to random error in hand force values

It can be seen from both Figures 28 and 30 that the effect of variability in hand force is slightly less than the effect of variability in postural analysis. Variability in hand force can cause an over-prediction of up to +14% and under-prediction of almost -13%, compared to corresponding values of +25% and -32% for random error of +/- 5° in postural analysis.

The effect of errors in cumulative dose due to the variance in trunk posture and hand force tends to be magnified by the exponent used in the model.

The hand force data acquired during the focus groups were collected using two methods: direct measure and force replication, the latter a method used by other researchers in the field (Kumar 1990, Norman *et al.* 1998, Daynard *et al.* 2001). In the present study, it is noted that there is considerable variance in hand force for some tasks. It is possible that with improved hand force measurement methods, the variance in hand force values would be smaller, thus decreasing the potential error in the model.

Discussion

The unique features of this model are that it is based on material properties of spinal structures, and that it predicts the probability of low back injury as a function of cumulative exposure to joint loading. Existing manual materials handling guidelines provide a relative risk of injury (Waters *et al.* 1993, Hidalgo *et al.* 1997, Shoaf *et al.* 1997) or a population percentile capable of performing the tasks (Snook & Ciriello 1991, Mital *et al.* 1993). These models do not predict probability of injury, hence are limited in their predictive value. Although this model is based on peak compressive loading of the L4/L5 joint, a similar model could be developed to predict fatigue failure due to shear loading. Additional information would be required on the failure properties of tissues under shear loading.

Fatigue Model Development

The use of a fatigue model for predicting low back injury to humans is not new (Payne 1992, Morrison *et al.* 1999, ISO 2004). These models assess the health effects of repeated shocks on workers exposed to vibration and shock during the course of their working life. What is novel about this study is the application of this model to manual handling tasks, using compressive loading experienced during patient handling tasks to represent the loading input into the model in place of whole-body vibration. In addition, the development of this model included the use of actual injury rates using historical injury data from a worker population. This step provides additional evidence and strength to support the utility of the model.

The model developed in this study uses both longitudinal and cross-sectional data. To validate this model, more accurate data obtained from longitudinal studies on "first-time" LBI incidence in the workforce is needed. Limited injury data were used to indicate the performance of this model. Clearly, this is an insufficient amount of data. Additional data would assist in the refinement of the model and a closer examination of the model's performance in different scenarios (i.e., changing shift task routines, changing work schedules, re-designing work tasks).

The model and associated methods have benefits in that an assessor is able to use inputs to the model that replicate current or historical work methods or proposed changes to work methods or job design. Changes can be assessed for their potential impact on risk of LBI on a "probability of injury" continuum, based on either worker age or years of work experience, whereas current models do not provide this type of information. Progressive steps in ergonomic intervention can be modelled to determine improvements in risk, thus allowing the effectiveness of changes to be measured. One scenario that could be examined is the common recommendation to decrease the load of an object handled by distributing the load over multiple lifts or carries. As this results in an increased frequency of load handling, the model could be utilised to examine whether the risk trade-off is effective. Which is worse: moving a heavy load once or lighter loads many times? When does the lighter load present a greater risk due to the required increase in handling frequency? When is the risk trade-off sufficient?

Ultimate Compressive Strength

The UCS used for the model is shown in Table 25 together with the corresponding values derived from the equation of Genaidy *et al.* (1993).

Table 25. UCS used in model development compared to predicted UCS

Age	Mughal (2004) (N)	Genaidy *et al.* (1993) (N)
34	7714.2	6961.8
35	7640.3	6888.1
40	7258.9	6519.6
45	6848.6	6151.1
50	6438.3	5782.6
55	6028.0	5414.1
60	5617.8	5045.6
65	5207.5	4677.1

The average difference between the UCS values calculated by Genaidy *et al.* (1993) and the values used in the model is 664N. This difference could be due to the possibility that the UCS determined by in-vitro studies of cadaver specimens underestimates the actual in-vivo UCS. Absence of supporting ligaments and musculature and involvement of additional forces (e.g., intra-abdominal pressure) may also play a role when comparing cadaver data to biomechanical estimates of spinal loading.

Fatigue Model Performance

When compared to the LBI statistics collected over the five year period, Figure 26 shows that the model under-predicts LBI rates between one and five years of work experience and over-predicts LBI rates in the later years of work experience. As injury statistics were available for only a five-year period, it is expected that a proportion of injuries reported for workers with more than five years work experience are not first time LBIs. This factor would bring the slope of the actual first time LBI data lower, and increase the difference between the model's output and the actual LBI rate.

The under-prediction at and below four years of work experience is partially a function of the methods used to fit the model to the injury data. The number of LBIs within the first five years of work experience was used to determine the UCS used in the model. Hence, it will act as a cross-over point if the actual injury incidence is different from the model prediction.

The over-prediction of the model in later years of work experience may be corrected by adjusting the standard deviation of UCS or by adjusting the exponent in the equation. Any adjustment to these parameters would require confirmation from data in the literature. Published data indicate the standard deviations in UCS determined with samples of cadaver specimens are within the range of 20% (Morrison *et al.* 1997), an assumption used in this study.

The over-prediction in later years may also be attributed to the possibility of a substantial proportion of LBIs in this period actually presenting as repeat LBIs. The cross-sectional data obtained is unable to confirm the presence of earlier LBIs for those individuals, and hence an error is likely present. However, based on the corrections made to the data analysed from the first five years of work experience, there is likely a proportion of individuals that are reporting their second or third LBI. If this correction were to be made, the slope of the actual injury rates in Figure 26 would be reduced, bringing it closer to the predicted levels of the fatigue model. Without more accurate data, however, this correction cannot be performed.

Another likely cause of over-prediction is the assumption of a linear relationship between age and spinal strength, as proposed by Genaidy *et al.* (1993). There is adequate data (Hansson *et al.* 1980, Porter *et al.* 1989) to show deterioration occurs in UCS in older adults, particularly women in the age range of 50-80. However, the rate of change in UCS for a younger adult population is less well defined.

If the UCS in the model is held constant within the age range of 34-61, the slope of the cumulative probability distribution will be much lower and the probability predicted by the model will fall below the actual injuries recorded in the five-year injury data set. This effect is shown in Figure 31 with the addition of a fatigue model plot using a constant UCS value.

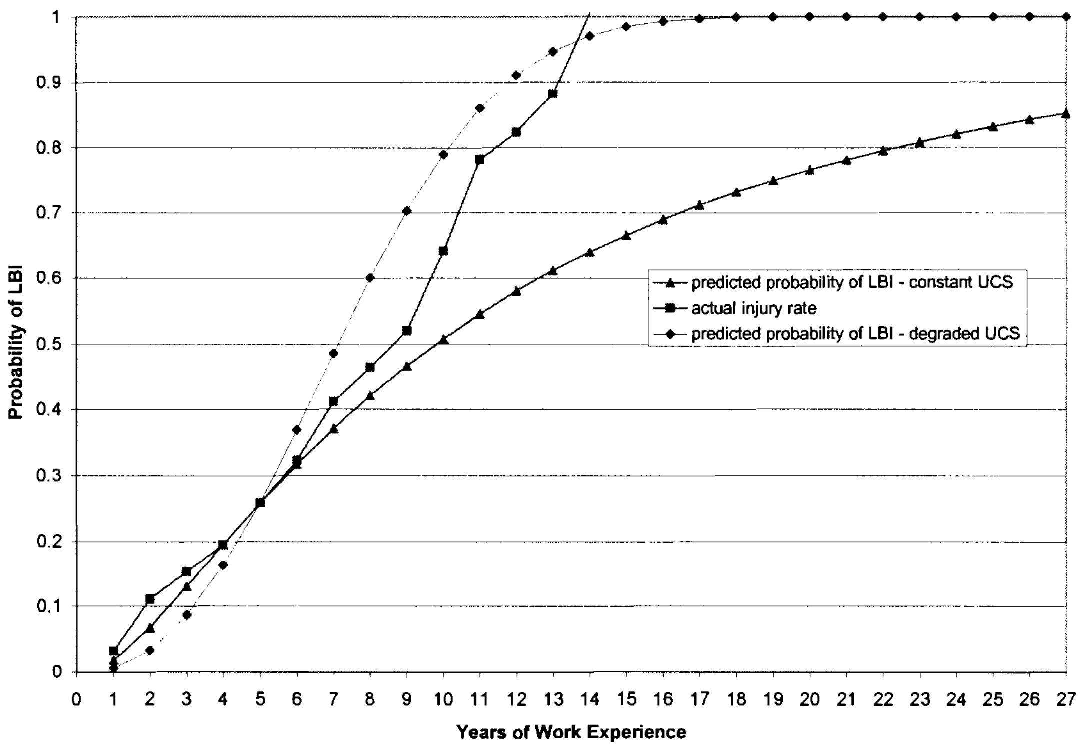

Figure 31. Plot of fatigue model with constant UCS, actual injury rates and fatigue model with degraded UCS

By using the fatigue model, it is possible to predict the probability of injury for workers within a particular age range. Figure 32 is a plot of the fatigue model in three different scenarios: workers hired at age 20, at age 30 and at age 40.

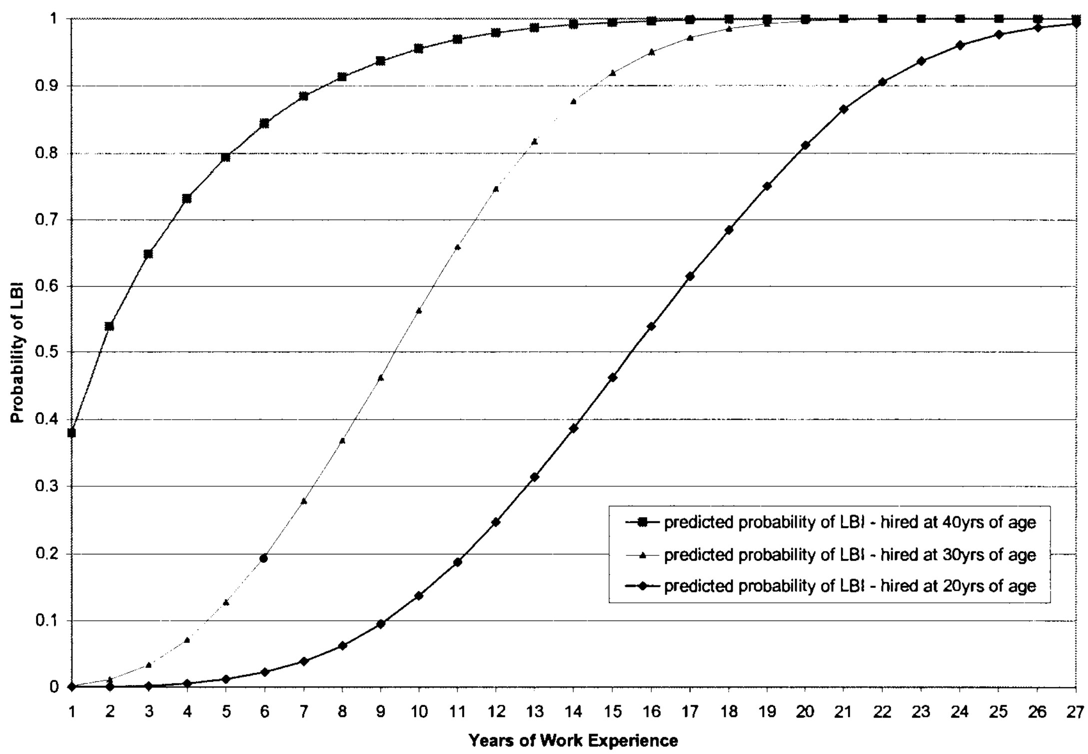

Figure 32. Plots of fatigue model with "age at time of hire" values of 20, 30 and 40 years of age

This has implications for the healthcare industry as a whole. The graphs in Figure 32 demonstrate the reduced risk of LBI associated with younger workers working in the same work environment. There is incentive for healthcare employers to recruit and retain workers from a younger age. This will not only reduce the rates of LBI and associated injury costs in the work unit, but it may also decrease utilisation of sick time due to workers staying at home due to signs and symptoms of LBI.

The model also presents more objective evaluation methods for workplace interventions aimed at retaining older workers. Scenarios can be evaluated to determine the effect on a particular age group within the working population.

As a tool, this model allows for the preliminary evaluation of any ergonomic intervention that involves the modification of work design, specifically the task profile, the frequencies of tasks and the compression forces involved in these tasks. These variables, along with the age group of the target worker population, can be modified within the model to determine effectiveness of each intervention prior to the financial and organizational costs involved in implementing change in the workplace.

Injury Data Analysis

The injury data obtained from the employer presented significant challenges with respect to data analysis. The inconsistent coding and completion of injury records made it difficult to accurately determine the portion of injury records that specifically involved the lower back. Assumptions were necessary in order to compile a set of data on which further analysis could be performed. Other challenges included the difficulty in accessing information regarding the hours worked by workers with different employment status, and the absence of data for workers who had left the organization at the time of analysis. Some corrections were possible, however these assumptions create a margin of error that is difficult to establish given the data currently available. This study, however, provides guidelines to employers with respect to the type of data collection that would be valuable. Given that new computer database systems and stronger injury tracking processes are available, further development and validation of this model will be possible in the near future.

Conclusions

A model to predict probability of low back injury was developed using material fatigue failure theory to explain development of low back injury as a function of exposure to work tasks. The model utilized injury data from a healthcare employer to refine the model's accuracy. The model has ability to examine effects of individual tasks and task redesign on the overall probability of low back injury, as well as the effects of work design on different age groups of workers. Further work is required to validate the performance of the model, particularly the acquisition of more longitudinal low back injury data.

Future research

There are a number of studies than can assist in the refinement of the fatigue model presented in this study. Development of a comprehensive historical injury profile for the resident care attendant workforce, including age at date of hire, date of first low back injury, and comprehensive work profile since start of working career can offer more accurate information upon which the fatigue model's behaviour can be based.

As mentioned above, scenario development and testing to examine the theoretical changes in LBI probability profiles as a function of various ergonomic interventions will be studied to evaluate the fatigue model behaviour. Due to the design of the model, effectiveness of ergonomic interventions are likely to be greater when tasks involving high compression forces are targeted, especially if these tasks are also frequent within the work design.

One of the shortcomings of the current models available in the literature is the lack of robust validation data on the changes to injury rates in industry in comparison to predictions made by the model. There are opportunities in the healthcare industry to examine the validity of this model over the long term, as interventions for LBI prevention are on-going, hiring practices are being refined and data is becoming more easily accessible. This can be accomplished through a prospective study of incidence of first low back injury among residential care workers from date of start of working career.

Validation of the fatigue model can be further enhanced through development of work profiles, model predictions and actual injury rates over a number of different industries. The methods described in Studies I and II were purposefully designed to allow for workplace data collection, allowing these methods to be used in other industries to evaluate the model's performance.

It is recognised that the mechanisms of low back injury are likely multifactorial. This model considers only peak compressive loading in its contribution of fatigue failure of the vertebral structures. A more comprehensive model would include such factors as shear loading, viscoelastic behaviours of the intervertebral disc and ligaments, load-time profiles and muscle fatigue. At this stage it is difficult to produce a comprehensive multifactorial model based on material properties without a better understanding of the ultimate strength of tissues and the interaction of creep, compression and shear loading. These issues represent areas of future research.

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LIMITATIONS

The limitations of this model are based on assumptions used in each of the steps taken to obtain parameters required for the development of the fatigue model.

The list of tasks typically performed on a residential care unit was modified from one focus group to the next. This variability in the tasks analysed, and varied numbers of data points for each task, may contribute to some inaccuracies.

The historical injury data obtained from the employer were difficult to accurately analyse due to inconsistent data entry methods used over the years, vague injury data, and a recent start-up of the electronic database for injury data tracking. These factors all contribute to an underestimation of the actual injury rates, especially in the first third of years of work experience.

The range in data obtained from full time staff versus the part time or causal staff presented difficulties in modeling injury risk. For simplicity's sake, injury data were modeled based on the assumption that a full year of work was performed in each calendar year of work experience. This is not likely accurate, in fact it likely leads to an underestimation of the rates of injury based on years of work experience. For a worker working less than full time hours, if they were injured after five years of work experience (from date of hire to date of injury), this would be equivalent to less than five years of full time work; if the worker were in a 0.5FTE position, that five year period would be equal to only 2.5 years, and hence should be contributing to the injury rates at the three-year level instead of the five-year level. Assuming that each worker in the data set has worked the number of shifts equivalent to a full time worker underestimates the rate of injury at earlier years of work experience.

Anecdotal evidence suggests that casual workers are likely to work as many, if not more hours in a pay period when compared to full time workers. This is due to the lack of paid holidays for casual staff, and the ability to work back-to-back shifts at multiple facilities. This type of work pattern would not be supported by a single employer, but there is no way to determine the number of hours worked in a given work week for causal staff that are employed at other hospitals or under another employer. It is likely that part time staff work less than full time workers, as many part time staff take on a part time line to enable them to maintain a shorter work week as part of a lifestyle decision.

The biomechanical model inputs included height and mass of the subject, as well as hand force values and the subject posture. While methods used to measure hand force and postural translation from video to software were also used in other published research (Norman *et al.* 1998, Daynard *et al.* 2001), validation of these methods are still absent from the literature. Potential errors exist in the accuracy with which subjects are able to replicate a dynamic force in a static fashion. Similarly, the accuracy with which postures can be replicated in a biomechanical software program based on still and video images is unknown. These issues present areas of further research that require detailed examination.

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